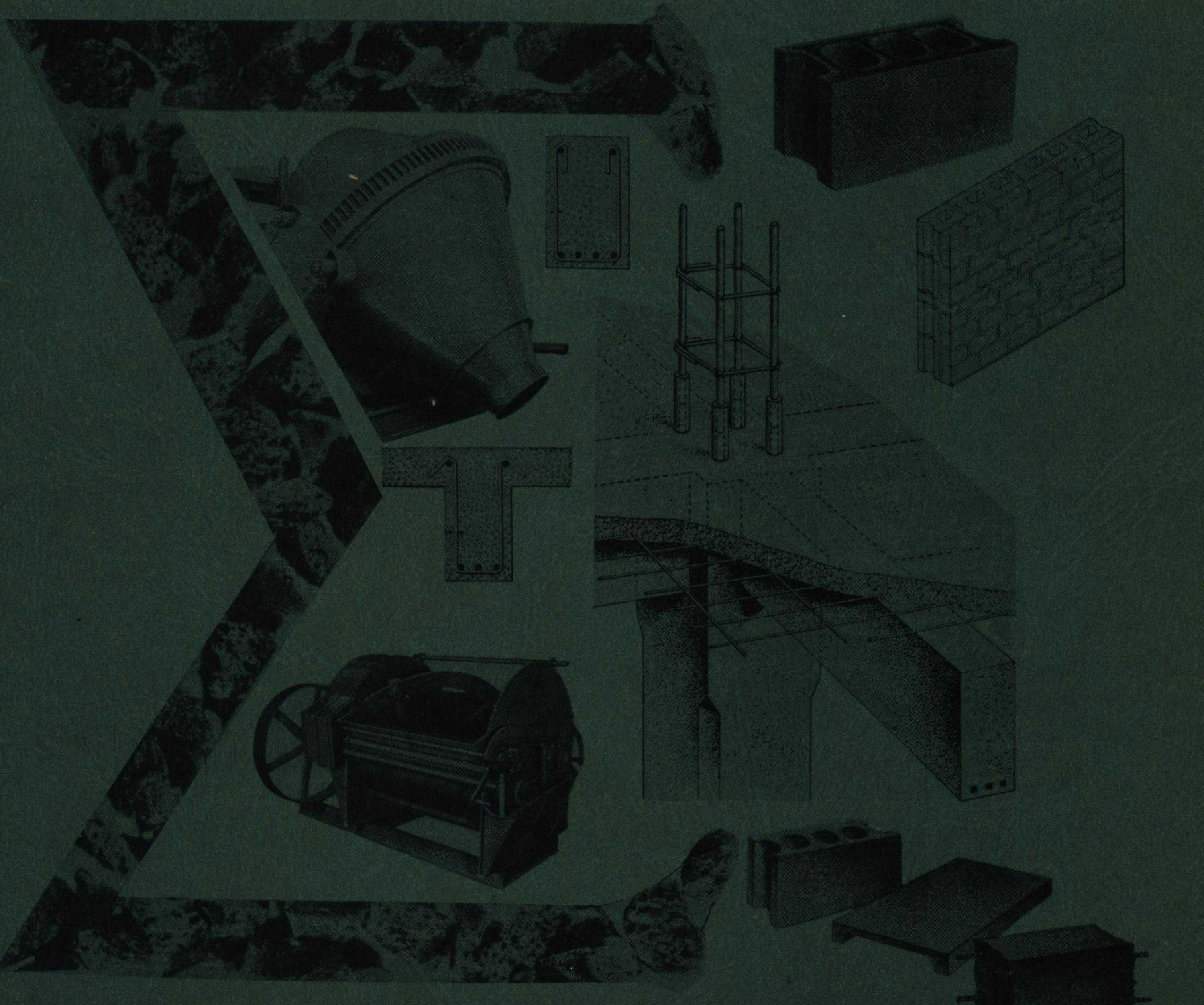
HAYDITE

The Lightweight Aggregate

MANUAL



A DATA BOOK FOR DESIGNING ENGINEERS AND ARCHITECTS

Compiled
by
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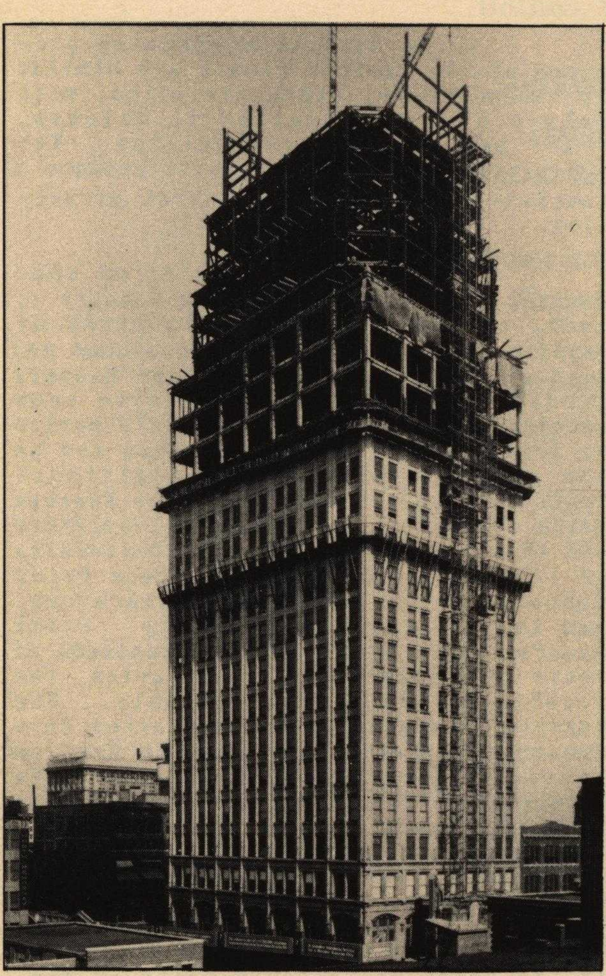
This extensive experimental work has enabled the Haydite industry to keep abreast of the progressive development in concrete making. Haydite aggregate concrete in all these tests has satisfactorily met all the requirements, including workability, economy, strength and durability, desirable in concrete.

Trade journals predominantly describe new construction, but seldom portray the behavior of any structure after a period of years. The Haydite industry has maintained constant observance of their many structures, and has available performance records of Haydite concrete, under the most severe conditions, for a continuous period of eighteen years. Anyone connected with the industry is prepared to substantiate its superior performance.

STRUCTURAL CONCRETE



Fourteen stories added
by use of
Haydite Concrete and Units

GENERAL

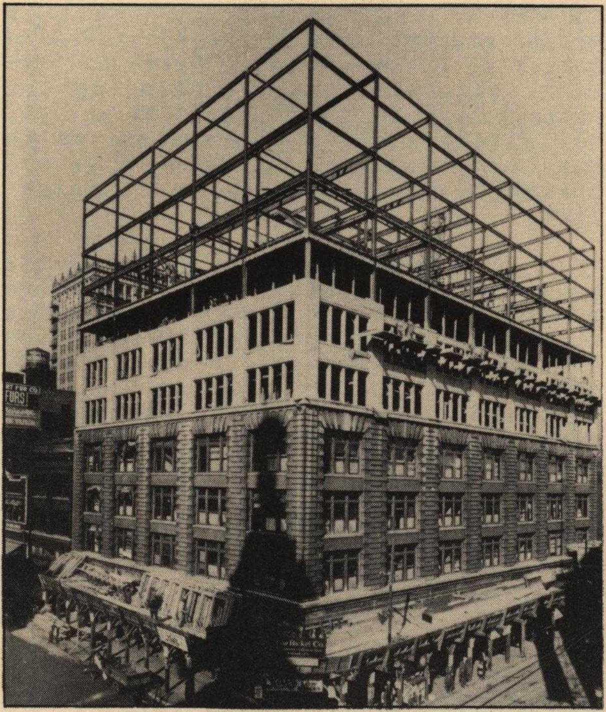
Haydite aggregate concrete averages 30% to 40% less in weight than concrete made with sand, gravel and/or crushed rock of normal specific gravity. With approximately the same amount of cement it produces concrete comparable in strength to concretes made with natural aggregates. For special uses a concrete weighing 70 pounds per cu. ft. has been produced with Haydite aggregate.

It finds its ideal use wherever lightness of weight is desirable and particularly in building conditions demanding reduction of dead load. Its lightness of weight makes it especially adaptable if it is desirable to increase the number of stories of a building and the size of floor panels. It follows that in structures of equal height, it permits a decrease in the cost of supporting trusses, columns, footings or other substructures.

There are many instances where the savings in cost of structures due to reduction in dead load resulting from the use of Haydite aggregate has amounted to more than three times the cost of the Haydite aggregate.

Haydite concrete possesses sound and heat insulation properties much superior to natural aggregate concrete.

Haydite has been extensively used in the construction of both reinforced concrete and structural steel



Eight stories added
by use of
Haydite Concrete and Units

frame buildings in the past twenty years. Nearly every city over 200,000 population in the United States and southern Canada has some Haydite concrete construction.

Haydite concrete being chemically inert assures full protection of steel incasements, reinforcing bars and metal lath.

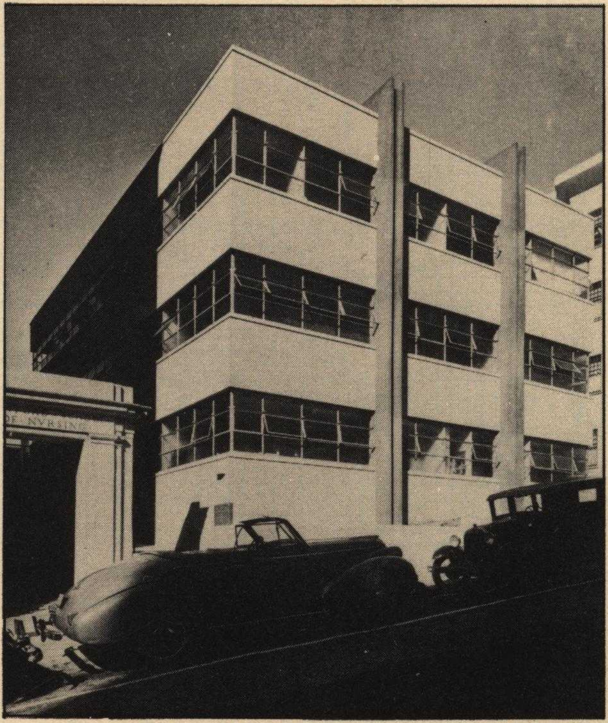
The increase in compressive strength, with age, of moist stored Haydite concrete compares well with that of natural aggregate concrete.

The ratio of bond resistance to compressive strength at 28-day age is essentially the same as for like mixes of natural aggregate concrete.

A resume of the experimental program conducted to determine the behavior of Haydite in concrete mix design has been given in the Introduction. These tests were originated very shortly after the material was first commercially manufactured and have progressed continuously thru the various theories developed for the production of concrete. This program represents a period of eighteen years, during each year of which there were from two to four tests in progress. These tests have extended into the new developments in concrete design including "Vacuum Concrete" and "Prestressed Reinforced Concrete", the results of which have been published in current issues of the A.C.I. Journal.

In the days when 1-2-4 natural aggregate concrete was presumed to develop a 28-day compressive strength of 2000 p.s.i., 1-3-3 Haydite concrete was produced with strengths of 2100 to 2400 p.s.i. It was then the custom to designate mixes in terms of volume proportions as: "One part Cement - Two parts Fine Aggregate - Four parts Coarse Aggregate", (1-2-4). This method of specifying concrete proportions is seldom used at the present time on large projects, but still has some use on small ones. The theory that proportions of aggregate and cement define strength is practically obsolete.

Early in the development of concrete mix design Taylor & Thompson devised a method of proportioning aggregates according to a mechanical analysis curve, which was termed their "Ideal Curve", and assumed that the proper proportioning of concrete materials increased the strength obtainable from a given amount of cement. Numerous tests conducted seemed to indicate that for the materials used there was a certain mixture of sizes of grains of the aggregate which, with a given percentage by weight of cement to the total aggregate, gave the highest breaking strength.



A novel design made possible
by Haydite Concrete

Later experiments have proven that this gain in strength was due to the fact that in correctly proportioning the aggregates the volume of water necessary to produce a workable concrete was reduced to a minimum and, therefore, gave strength in excess of that produced by merely arbitrary proportions.

Professor Duff Abrams in an attempt to devise a more workable method of proportioning discovered his "Water-Cement Ration Law."

The hundreds of thousands of tests conducted by which the water-cement ratio law was established and the confirmation of that Law by the millions of cubic yards of concrete poured since its acceptance confirm beyond doubt that the deciding factor of concrete strength is the ratio of the mixing water to the cement. This holds true only so long as the mixture is plastic and workable. Practice has variously used this ratio in terms of volume: cubic foot of water to cubic foot of cement; and in terms of weight: pounds of water to pounds of cement; either of which may be converted to: U. S. Gallons of water per 94 pound sack of cement.

The research of Abrams was performed during a period when concrete ingredients were measured by volume. Water cement ratio is still defined in terms of volume by some engineers, and is occasionally found in test data. Current practice proportions aggregates by weight and defines w/c ratio by weight proportions. An accidental discovery of Professor Lyse, Leigh University, indicated that in changing the relation w/c to c/w in terms of weight, the strength value of concrete as an equation expressed in terms of an exponential variable plats as a straight line.

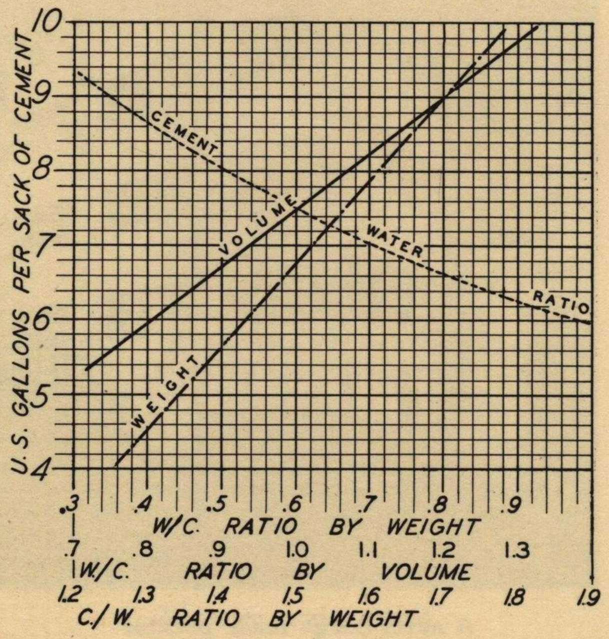


Fig. 1

In dealing with concrete mix design, particularly in the comparison of various test data, there is need of a ready means of conversion of the three methods of expression. Figure 1 shows comparative values reflecting the three ratios in terms of U. S. Gallons of water per sack of cement.

UNIVERSITY OF ILLINOIS TESTS

After Abrams' "Water-Cement Ratio Law" became accepted and recognized as the method of mix design, extensive tests (sponsored by the Western Brick Company), were conducted at the University of Illinois and published as Bulletin No. 237. In these tests the aggregate proportions were by volume and corresponded closely to the arbitrary proportion rule, but the mixing water was carefully governed by the Water-Cement Ratio Law.

In the University of Illinois tests 324 cylinders using Haydite as the Fine and Coarse aggregate were broken to constitute two series, defined as "Dry Series" and "Wet Series" and presented here as Tables I and II. The tabulated values under each w/c ratio, mix proportion, and compressive strengths at 7-day and 28-day are the average of three tests. The tests included in Table I (Illinois Series A-3) and Table II (Illinois Series A-2) furnish an extreme range in aggregate moisture condition, those in Table I using oven dry aggregates and those in Table II an aggregate with an unusually high moisture content. These tabulated results reflect the variation of strengths for various w/c ratios, and the variation of consistencies, in terms of Slump, obtained for various proportions of aggregate and cement. Also the quantities of aggregate required, both in terms of "loose dry" and "loose moist" measure of aggregate, to produce a cubic yard of finished concrete of the consistency and strength evidenced in the tables.

Mix	Water-Cement Ratio by Volume	Slump in Inches	Unit Weight of Fresh Concrete Lb. per cu. ft.	Compressive Strength Pounds per sq. inch		Quantities Required per Cubic Yard of Concrete		
				7-day Cylinders	28-day Cylinders	Cement bbl.	Fine Haydite "A" cu. yd. loose dry	Coarse Haydite "C" cu. yd. loose dry
1:1½:2½	0.86 0.96 1.06	5.4 6.6 9.6	99.0 96.8 96.3	1990 1500 1160	3700 3060 2440	1.86 1.79 1.75	0.41 0.40 0.39	0.69 0.66 0.65
1:2:2..	0.88 0.98 1.08	5.5 7.5 9.9	99.5 97.6 97.1	1880 1460 1210	3470 2890 2490	1.83 1.77 1.73	0.54 0.52 0.51	0.54 0.52 0.51
1:2½:1½	0.90 1.00 1.10	3.1 6.6 9.7	99.6 98.6 97.7	1850 1470 1060	3320 2770 2150	1.79 1.75 1.70	0.66 0.65 0.63	0.40 0.39 0.38
1:2:3..	1.01 1.11 1.21	1.9 5.3 8.4	95.9 95.1 94.8	1370 1160 870	2530 2300 1920	1.53 1.50 1.47	0.45 0.44 0.44	0.68 0.67 0.65
1:2½:2½	1.03 1.13 1.23	1.7 5.4 7.7	96.2 96.9 95.7	1250 1070 900	2620 2310 2060	1.51 1.50 1.46	0.56 0.56 0.54	0.56 0.56 0.54
1:3:2..	1.14 1.24 1.34	3.0 7.2 8.2	97.1 96.0 94.8	1120 870 670	2350 1960 1310	1.47 1.44 1.40	0.66 0.64 0.62	0.44 0.43 0.42
1:2½:3½	1.25 1.35 1.45	1.0 7.4 7.6	95.0 94.7 92.6	750 760 540	1580 1680 1310	1.30 1.28 1.24	0.48 0.48 0.46	0.68 0.67 0.64
1:3:3..	1.27 1.37 1.47	2.7 5.3 6.7	95.2 95.8 93.0	820 710 540	1760 1620 1280	1.29 1.28 1.23	0.57 0.57 0.55	0.57 0.57 0.55
1:3½:2½	1.39 1.49 1.59	2.7 3.3 6.9	95.7 94.7 93.9	640 560 470	1470 1220 1110	1.26 1.23 1.21	0.65 0.64 0.62	0.47 0.46 0.46

Table I

In commenting on a tabulation extracted from Bulletin 237 (A.C.I. Journal October 1930), Professor Richart says:

"Data . . . are given in Table 2 as a guide to proportions and accompanying slumps useable with various water-ratios. The materials used were in all cases initially dry. If moist aggregates are to be used, bulking and moisture content tests should be made, so that volumes of moist material containing solids equal to those of the dry materials may be used. The bulking effect is small for the coarse Haydite and usually will not exceed 5 or 6%, but for the fine Haydite the bulking may be important. Thus the fine Haydite weighing 55 lb. per cu. ft. by dry loose measure, weighs 51 lb. per cu. ft. with 27 per cent of moisture present. This 51 lb. consists of 40.1 lb. of dry Haydite and 10.9 lb. of water. To obtain 55 lb. of dry Haydite in the mixture requires 55/40.1 or 1.37 cu. ft. of the moist material. With this 37 per cent bulking in the fine aggregate and assuming a 5 per cent bulking in the coarse, for a mix of 1:2:3 concrete as listed in Table 2, the volume proportions with the moist materials should be 1:2.74:3.15. Similarly, the quantities required per cubic yard of concrete as given in Table 2 would be multiplied by the ratios of 1.37 and 1.05 for the fine and coarse materials, respectively.

Mix	Water-Cement Ratio by Volume	Slump in Inches	Unit Weight of Fresh Concrete Lb. per cu. ft.	Compressive Strength Pounds per sq. inch		Quantities Required per Cubic Yard of Concrete		
				7-day Cylinders	28-day Cylinders	Cement bbl.	Fine Haydite "A" cu. yd. loose moist	Coarse Haydite "C" cu. yd. loose moist
1:1½:2½	0.77	3.0	104.9	2850	4510	2.12	0.47	0.79
	0.87	6.5	103.3	2230	3690	2.05	0.46	0.76
	0.97	9.5	99.8	1340	2710	1.95	0.43	0.72
1:2:2..	0.77	2.3	105.8	3180	4550	2.15	0.64	0.64
	0.87	8.3	105.1	2410	4050	2.09	0.62	0.62
	0.97	10.0	101.5	1490	2870	1.98	0.59	0.59
1:2½:1½	0.78	1.2	106.3	3240	4810	2.16	0.80	0.48
	0.88	8.1	106.2	2660	4550	2.11	0.78	0.47
	0.98	10.5	103.6	1460	2990	2.02	0.75	0.45
1:2:3..	0.89	1.4	101.9	2150	3690	1.76	0.52	0.78
	0.99	2.5	101.5	1670	3250	1.73	0.51	0.77
	1.09	7.5	100.1	1350	2820	1.68	0.50	0.75
1:2½:2½	0.90	1.3	102.8	2320	3780	1.79	0.66	0.66
	1.00	3.5	102.9	1900	3600	1.76	0.65	0.65
	1.10	7.2	101.1	1590	3060	1.70	0.63	0.63
1:3:2..	1.00	2.8	103.8	1810	3330	1.78	0.79	0.53
	1.10	6.5	103.0	1600	3130	1.70	0.76	0.51
	1.20	8.6	102.3	1220	2430	1.70	0.75	0.51
1:2½:3½	1.10	1.4	98.9	1360	2620	1.48	0.55	0.77
	1.20	5.2	99.3	1000	2040	1.47	0.55	0.76
	1.30	7.7	99.1	800	1790	1.45	0.54	0.75
1:3:3..	1.11	1.5	100.7	1460	2880	1.51	0.67	0.67
	1.21	5.0	99.2	1090	2270	1.47	0.65	0.65
	1.31	7.0	99.8	1040	1970	1.46	0.65	0.65
1:3½:2½	1.22	4.0	99.8	1150	2450	1.48	0.77	0.55
	1.32	7.7	100.2	900	1890	1.46	0.76	0.54
	1.42	8.8	100.9	860	1770	1.46	0.76	0.54

Table II

"The use of moist aggregates just described will naturally affect the water requirements. In a one-bag batch the 2.74 cu. ft. of fine aggregate contain 10.9 lb. of water per cu. ft. or 29.9 lb. This must be considered in computing the amount of water for mixing and absorption requirements.

"The quantities of materials in Table 2 contain no allowance for waste or for settlement of material in forms. As explained, the aggregate quantities must be increased for bulking when moist aggregates are used. If these proportions are used without correction for bulking, a richer and stronger mix will result, and all quantities of materials, including the cement, will be increased. The amount of such increase, in per cent, is roughly equal to the per cent bulking of the fine aggregate times the ratio of fine to total aggregates.

"Table 2 shows a range of workabilities as shown by values of Slump from 1 to 10 inches. For making test beams with fairly heavy reinforcement, very satisfactory placing of the concrete was accomplished with slumps of 6 and 7 inches. Good surfaces were obtained next to the forms and there was practically no honey-combing or segregation of the materials. For slabs and large beams slumps of 4 to 6 inches should give satisfactory workability."

Professor Richart's comment referring to his Table 2 applies, likewise, to the University of Illinois Series, (A-3).

A careful analysis of Tables I and II will indicate the conformity of concrete produced from Haydite aggregate to the w/c ratio law. While individual instances reflect values both above and below the water-cement ratio strength curve for normal portland cement, a mean of all the values conforms closely to this curve.

The variation in the mixes is reflected by the slump in inches and by the cement factor in barrels per cubic yard.

The mixes showing extreme deviation from the normal curve are mixes of low slumps where the paste content of the mass was reduced, decreasing the water content of the entire mass to a minimum, allowing the aggregate to absorb some percentage of water from the paste, thus producing a paste with a strength in excess of the designed amount. This extreme variation from a median line is less evident in Table I.

The University of Illinois tests were made using a new lot of standard Universal portland cement, passing the Standard Specifications for cement in use when the tests were made (1931). The strength agrees with the strength of concrete produced from present day (1938) portland cement. The curves published on strength relation by Professor Abrams were based on strengths of concrete produced with a lower strength portland cement with a resulting lower strength value. The improvement in compressive strength is the result of modified chemical composition, improved manufacturing processes and greater fineness of grinding, voluntarily adopted by the cement industry in order to compete with the production of high early strength cements.

Experiments conducted by the Port of New York Authority in 1939 established a strength value approximately one and one-half times greater than the strength reflected in the original Abrams' publication. The curves developed by the PNYA are slightly higher than those shown in P.C.A. publication T-12 (revised 1938). The division line in cement strengths is set by some authors at 1928. In platting the results of both tables as strength against water-cement ratio there are several points not in conformity to the median line evidencing strengths far in excess of the theoretical "strength curve."

Mix Proportions by Weight	Water Cement Ratio by Wght.	Total Water inc. abs. gals. /sk.	Cement sacks/ C.Y.	Wet Unit Wght.	Strength lb/s.i. 7-day	Strength lb/s.i. 28-day	Aggregate Quantities to produce one C.Y. of finished concrete: Fine	Med.	Coarse
1-1.68- .84- .28	0.57	8.83	6.5	103.9	1967	3372	1025	513	171
1-1.26- .63- .21	0.47	7.06	8.0	104.2	2853	4135	946	473	158
1-0.71- .36- .12	0.39	5.85	10.9	103.3	4183	5455	730	365	123
1-0.96- .48- .16	0.39	5.76	10.0	108.0	3804	4691	900	450	150
1-2.10-1.05- .35	0.62	10.00	5.6	104.5	1600	2650	1100	550	183
1-0.71- .36- .12	0.33	4.78	12.5	113.6	4606	6147	835	418	139
				Est. Unit Wght. lb/ c.f.	Design Strgth. at 28 days		Computed Aggregate lbs./Cy.Yd.Conc.		
1-2.54-1.27- .42		13.00	4.7	98.0	2000 lb/s.i.		1122	561	187
1-1.85- .92- .31		10.00	6.0	102.0	3000 lb/s.i.		1040	520	173
1-1.33- .67- .22		8.00	7.6	104.0	4000 lb/s.i.		952	476	159
1-0.96- .48- .16		6.25	10.0	110.0	5000 lb/s.i.		906	453	151
1-0.72- .36- .12		4.75	12.5	114.0	6000 lb/s.i.		845	422	141

Table III

This variation is particularly evident in Table II and may be attributed to inaccurate absorption.

UNIVERSITY OF WYOMING TESTS

Joseph A. Kitts, a well-known concrete technician of the Pacific Coast, conceived the idea of concrete mix design using an ideal grading of aggregates in combination with the w/c ratio (CONCRETE, Nov.-Dec. 1931). The economic result from the acceptance of Kitts' theory encouraged the American Aggregate Company to initiate a series of tests at the University of Wyoming to determine the proportions of Haydite aggregate necessary to produce a workable concrete with a minimum cement content and to determine the w/c ratio law applicable to Haydite aggregate thru a considerable strength range. The results of this series of tests, giving the quantities used to produce a workable mix, appear in Table III. In addition to the w/c ratio producing compressive strengths of 2000 to 6000 p.s.i., there are included computed values of the total water and the quantities of aggregate in pounds required to produce workable concretes of predetermined strengths.

The weights required to produce one finished yard of Haydite concrete are calculated for a material with a "Loose" unit weight of:

Fine	=	65 pounds per cu. ft.
Intermediate	=	38 pounds per cu. ft.
Coarse	=	34 pounds per cu. ft.

The material had a dry rodded weight of:

Fine	=	67 pounds per cu. ft.
Intermediate	=	47 pounds per cu. ft.
Coarse	=	40 pounds per cu. ft.

The amounts of the materials required, for aggregate varying more than 1% either way from the above dry rodded unit weights, can be calculated by dividing the amount shown in Table III by the above unit weights and multiplying by the unit weights of the aggregate to be used.

LOW STRENGTHS

The information in Table IV for strengths lower than those shown in either the Illinois or the Wyoming tests, was assembled by Mr. Roy Peck, of the Western Brick Company, from tests taken on actual concrete jobs over a period of time. The values of the w/c ratios and strengths shown in Table IV are platted against a theoretical strength curve, (Figure 2).

Proportions by Volume (Loose)	Strength at 28 Day Age P.S.I.	Wt. of Dry Concrete Lbs./Cu.Ft.	Materials Required per Cubic Yard of Mixed Concrete: Cement		Haydite: Fine		Coarse		Total	Water: W-C Ratio by Vol.	Gal. per Sack Cement
			BBLS.	SACKS	CU. YD.	CU. FT.	CU. YD.	CU. FT.	CU. YD.		
1-3½ - 2½	2450	89 92	1.48	5.92	.77	20.8	.55	14.8	1.32	1.22	9.13
1-3-3	2880	88 91	1.51	6.04	.67	18.1	.67	18.1	1.34	1.11	8.31
1-2½ - 3½	2620	87 90	1.48	5.92	.55	14.8	.77	20.6	1.32	1.10	8.23
1-4-3	1625	85 88	1.34	5.36	.79	21.4	.59	16.0	1.38	1.28	9.57
1-3½ - 3½	1750	83 86	1.30	5.20	.67	18.2	.67	18.2	1.35	1.25	9.35
1-3-4	1875	79 83	1.27	5.08	.56	15.2	.75	20.3	1.31	1.22	9.13
1-5-3	1375	86 90	1.20	4.80	.89	24.0	.53	14.4	1.42	1.45	10.85
1-4-4	1500	81 85	1.16	4.64	.69	18.6	.69	18.6	1.38	1.40	10.47
1-3-5	1600	77 81	1.12	4.48	.50	13.4	.83	22.4	1.33	1.35	10.10
1-5-4	1050	84 87	1.08	4.32	.80	21.6	.64	17.3	1.44	1.60	11.97
1-4½ - 4½	1200	80 83	1.03	4.12	.69	18.5	.69	18.5	1.37	1.55	11.60
1-4-5	1250	77 80	.99	3.96	.59	15.9	.74	19.8	1.33	1.50	11.22
1-6-4	937	80 83	.94	3.76	.83	22.6	.55	15.0	1.38	1.80	13.47
1-5-5	958	77 80	.91	3.64	.67	18.2	.67	18.2	1.35	1.75	13.10
1-4-6	970	75 78	.90	3.60	.53	14.4	.70	21.6	1.33	1.70	12.72
1-7-5	600	76 80	.78	3.12	.81	21.8	.58	15.6	1.39	2.05	15.32
1-6-6	650	76 79	.77	3.08	.68	18.5	.68	18.5	1.37	2.00	14.96
1-5-7	690	73 77	.75	3.00	.55	15.0	.78	21.0	1.33	1.95	14.57
1-8-6	450	72 75	.65	2.60	.77	20.8	.58	15.6	1.36	2.35	17.60

Basic Weights: Fine (A) 1350 #/c.y. Medium (B) 1225 #/c.y. Coarse (C) 1100 #/c.y.
" 50.0 #/c.f. " 45.4 #/c.f. " 40.8 #/c.f.

Table IV

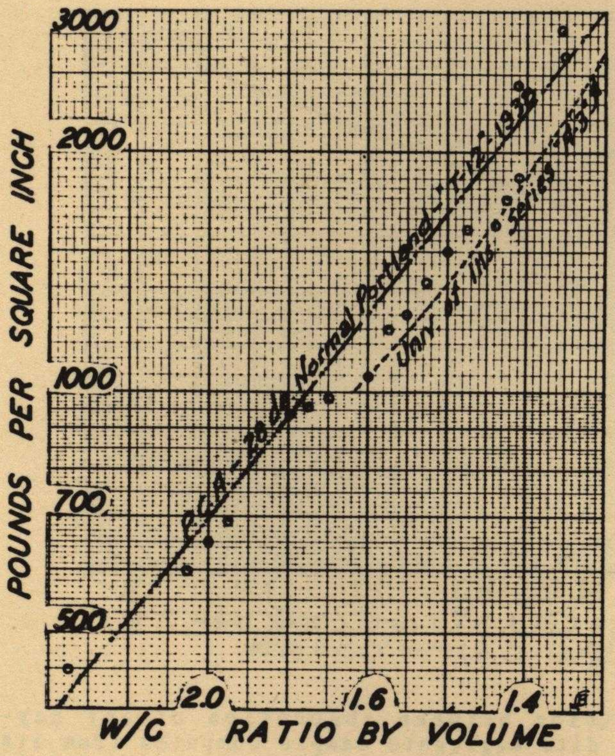


Fig. 2

CEMENT CONTENT

In the Abrams' w/c ratio law "for given materials and conditions of manipulation, the strength of concrete is determined solely by the ratio of the volume of mixing water to the volume of cement so long as the mixture is plastic and workable", the phrase "so long as the mixture is plastic and workable" contributes to the Cement Content Law.

Kennedy suggests (A.C.I. Journal February 1940) amending Abrams' law to read:

"The strength of Concrete is determined by the amount of mixing water, as long as the volume of cement paste is sufficient to fill the voids in the dry rodded mixed aggregate and to provide an excess proportional to the surface area of the aggregate."

and further states:

"The fundamental law of the workability of the mix is this: for a mix to be workable, the volume of cement paste, -- i.e., the absolute volume of the cement plus the volume of the mixing water, -- must be at least equal to the volume of the voids in the dry rodded mixed aggregate.

"Concrete in which the volume of cement paste was no more than equal to the volume of voids would be workable only under a strictly laboratory definition; it would have a slump theoretically equal to zero. For practical purposes, an excess of cement paste is required.

"The second law of the workability of the mix is this: for any required degree of workability, the necessary excess of cement paste depends (a) upon the consistency of the cement paste itself, -- lower water-cement ratios requiring larger excess amounts than higher ratios, -- and (b) upon the surface area of the aggregate, -- the larger the surface area, the greater the excess required."

It is apparent that if a fluid mix is made stiffer either by using less water and incidentally lowering the w/c ratio or by adding more aggregate without changing the w/c ratio, the plasticity of the mass is directly affected. Low w/c ratio and minimum cement content are opposing factors in a concrete mix and the two must be balanced to obtain a placeable mass. With Haydite aggregate, which of necessity is a harsh material, this balance cannot be regulated as conveniently by changing the particles of aggregate as it can in natural aggregate concrete.

In Haydite concrete the cement content must vary with strength as the plasticity of the mass is governed principally by the amount of paste. The cement in the mixture, therefore, contributes to the strength factor inasmuch as it is the developing agent of plasticity. While not deviating from the w/c ratio law a paste reduced in water content to meet a higher strength basis is not sufficiently fluid to form a workable mass and, if plasticity is kept within practical confines, the strength must be governed by the cement content which in turn is governed by the w/c ratio.

This factor is evident in view of the results shown in Tables II and III. In one test listed in Table II a slump of 10" was obtained with a cement factor of 1.98 bbls. p.c.y. using a water cement ratio of .97 (7.3 gals.) and developing a 28-day strength of 2870 lbs. In one test listed in Table III a workable concrete of approximately the same strength with a plasticity sufficient for placement under ordinary conditions was obtained with a cement factor of 1.41 bbls. p.c.y.

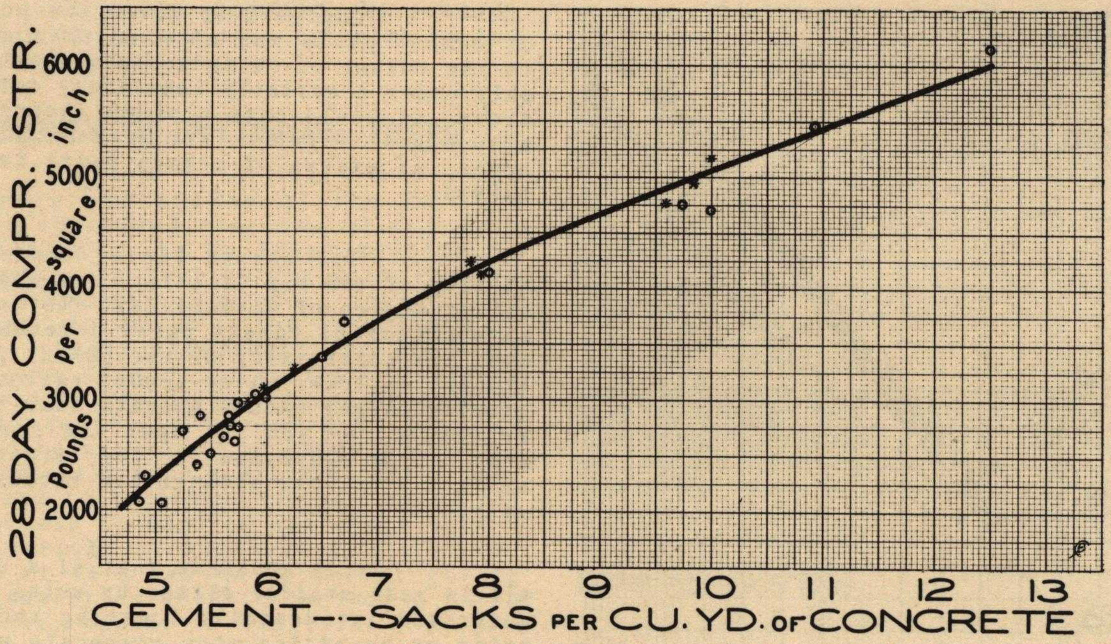


Fig. 3

Using the results of the University of Wyoming tests, a cement content curve is shown in Figure 3. This curve shows the cement content required for various strengths. In these experiments the consistency was held to the term "workable", the term "workable" being defined as "If concrete were of a nature that it could be placed in forms around reinforcing steel by the ordinary methods of placement, it was assumed to be 'workable' without reference to the recognized slump applicable to concrete mixtures using natural aggregates."

MIXING WATER

The absorption of mixing water, usually a minor factor in the production of concrete with sand, gravel or stone aggregates, becomes a matter of real importance when the aggregates are capable of absorbing a large amount of water. It is clear that Haydite aggregate does not have a fixed amount of absorption in a given time, as usually assumed for ordinary aggregates.

Extensive experiments have shown the absorption of Haydite to be dependent upon the fineness and initial moisture content. Fine Haydite absorbs more readily than the coarser sizes. Moist aggregates absorb more total water in a given time than those that are initially dry. There is also a variation between absorption of any Haydite aggregate sample computed from its sieve analysis, as the summation of the weights of each size times the corresponding absorption percentages, and various artificial mixtures of fine aggregate made up and their absorption found experimentally by the use of the specific gravity bottle.

There is little information regarding the period of time that aggregates should be immersed in water to produce an absorption equal to that taking place during the mixing and placing of concrete.

In commenting on the tests, reproduced here as Tables I and II, Professor Richart stated: "All of the points fall within a narrow zone on the diagram." (Figure 6, Bul. 237.). The results of the tests conducted at the University of Wyoming also conform closely to theoretical values of the w/c ratio.

By computing the Total Mixing Water from a summation of net water-cement ratio and amount allowed for absorption for the total number of tests at both the University of Illinois and the University of Wyoming, which data comprises tests of approximately 500 cylinders, the curve in Figure 4 was platted to show the relationship between strengths and mixing water per sack of cement.

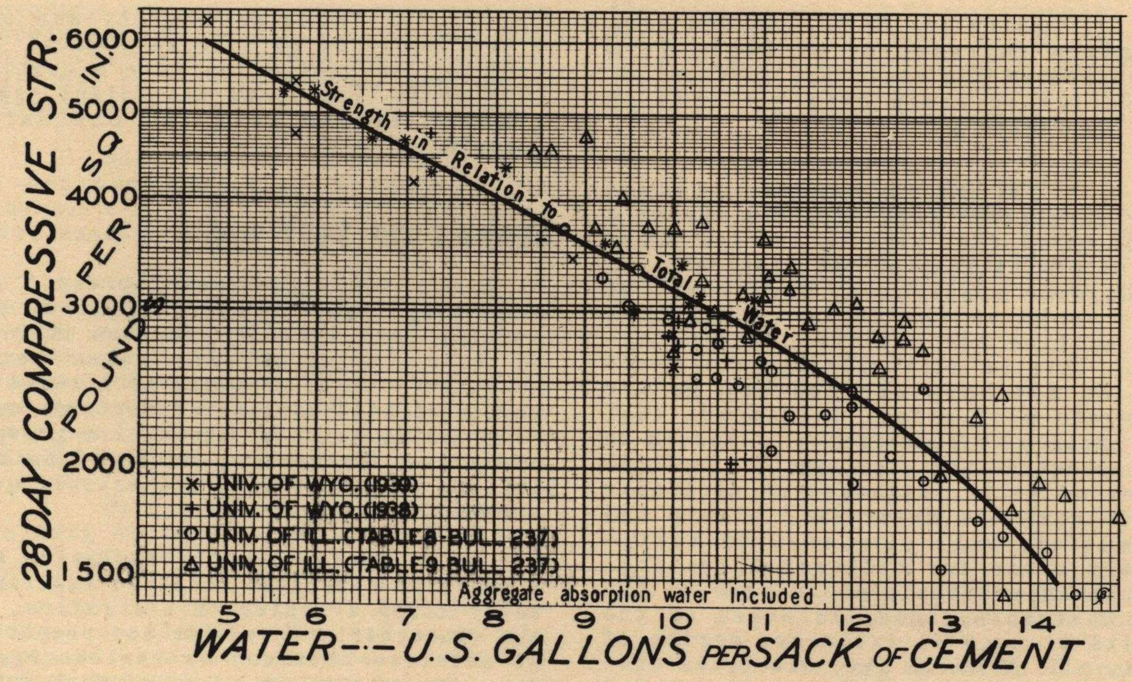

28 DAY COMPRESSIVE STR. POUNDS PER SQ IN.
6000
5000
4000
3000
2000
1500
Strength in Relation to Total Water
× UNIV. OF WYO. (1939)
+ UNIV. OF WYO. (1938)
○ UNIV. OF ILL. (TABLE 8-BULL. 237)
△ UNIV. OF ILL. (TABLE 9-BULL. 237)
Aggregate absorption water Included
5 6 7 8 9 10 11 12 13 14
WATER — U. S. GALLONS PER SACK OF CEMENT

Fig. 4

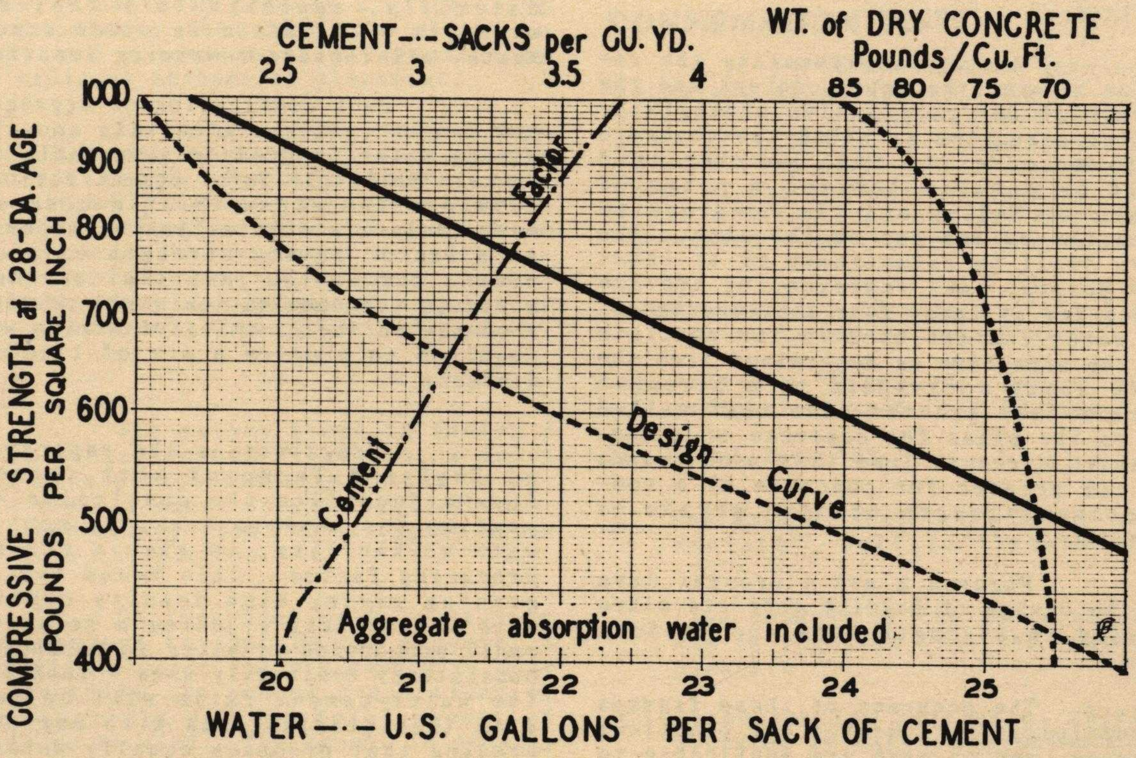

CEMENT — SACKS per CU. YD.
2.5 3 3.5 4
WT. of DRY CONCRETE Pounds/Cu. Ft.
85 80 75 70
COMPRESSIVE STRENGTH at 28-DA. AGE POUNDS PER SQUARE INCH
1000
900
800
700
600
500
400
Cement Factor
Design Curve
Aggregate absorption water included
20 21 22 23 24 25
WATER — U.S. GALLONS PER SACK OF CEMENT

Fig. 5

Using the data obtained from the mixes represented by Table IV a graph showing the essential features of Mix Design in low strength values is shown by Figure 5.

Except in certain places, under particular circumstances, or on a job of sufficient size to justify accurate determinations of the absorption of the Haydite aggregates, the amount of water shown by the curve in Figure 4 will suffice for Haydite concrete design. This is particularly true inasmuch as any moisture content in the aggregate will offset the amount that that particular aggregate will absorb to such an extent that the use of the Total Amount of Water, without the necessity of dividing the water into mixing and absorption, will give results sufficiently close for ordinary operation. This is especially true in view of the fact that this figure is based on the results of such an extensive series of tests, all of which give strengths considerably above the values recommended by the Joint Building Code of the A.C.I. for use with average materials.

The A.C.I. 1936 Building Code sets out strengths for various amounts of mixing water and specifies that a variation of the proportions of the materials and water content may be used, provided:

"A curve representing the relation between the water content and the average 28-day compressive strength or earlier strengths at which the concrete is to receive its full working load shall be established for a range of values including all the compressive strengths called for on the plan. The curve shall be established by at least four points, each representing average values for at least four test specimens. The water content used in the concrete for the structure as determined from the curve shall correspond to a strength which is 20% greater than that called for on the plans for concrete of a compressive strength less than 2500 pounds and 15% greater for concrete of a compressive strength of 2500 pounds or more."

Figures 4 and 5 present data for the design of Haydite concrete mixes varying in strength from 400 to 6000 p.s.i.

The accuracy of these figures is sufficiently close for all practical purposes, and as such are applicable to all Haydite aggregates. This statement is based on the fact that the curves were derived from results of tests using aggregates, both separately and combined, produced by several plants. For example, several mixes were a combination of St. Louis and San Rafael aggregates: Kansas City and San Rafael aggregates, etc.

RESUME OF TEST DATA

While we have progressed successfully from the old "arbitrary proportion law" thru the various theories of proportions to the "water cement ratio law" there are many architects and engineers today designing mixtures using some modification of the entire group of theories. Therefore, data, to be useable to all, must show convertible quantities.

Tables I to IV inclusive show a range of strengths obtained experimentally using a series of w/c ratios, and the characteristic yields and properties of concrete obtained by various aggregate proportions in terms of both volume and weight. Each test gives the proportions used and is, therefore, adaptable to those who are still designing by "arbitrary proportion rules." It is an indisputable fact that the strength of the paste governs the strength of the mass and that, if a certain strength can be obtained by a definite combination of materials, approximately that same strength will obtain in other experiments, all factors remaining identical.

Each combination of aggregates and cement requires a certain amount of mixing water to produce a workable concrete. While the water cement ratio determines the strength of a concrete, nevertheless a combination of materials is a factor in the strength of a concrete, due to the fact that any deviation in the combination would result in a change in the quantity of mixing water required to produce a mix of like consistency.

Coordinating the experiments of Taylor & Thompson with those of Abrams justifies the conclusion that grading for maximum density, combined with workability, is also a strength producing factor. This means that the grading giving high density combined with workability requires a relatively small proportion of water to produce the consistency ordinarily used. Therefore, the water-cement ratio will be lower with this grading than with any other grading that produces equally workable concrete of the same cement content and consistency. If the mix has more fine aggregate, more water will be required

to produce the same consistency, and the concrete will be weaker. If it has less fines, the concrete may require less water, but it will be harsher and insufficiently workable.

Some authorities maintain that the minimum amount of water will be required for a mix coarser than that giving maximum density.

By accepting the theory of density grading, the tables are made useable to those who still conform to the arbitrary proportion rule. The experiments have covered a sufficient range to define the workability of various mixes in terms of aggregate proportions as well as in terms of w/c ratio.

Professors Richart and Jensen, referring to results shown in Tables I and II, recommend:

"In the design of Haydite Concrete to be placed under ordinary conditions of supervision where careful absorption determinations are not made, it would be advisable to assume strengths of perhaps 80% of those given."

The workability of the concrete in the University of Illinois tests is given in terms of Slump. In the University of Wyoming tests, aggregates were combined with a predetermined strength paste to produce a concrete of a consistency that could be placed in forms and around reinforcing steel by the ordinary methods of placement.

The conclusions reached were only in terms of compressive strength and, although there is no definite relationship between the compressive strength and other physical properties of concrete, the strength in compression, for concrete containing similar ingredients, is a reasonable index of the quality of other physical properties.

The values shown in Tables I to IV inclusive and Figures 3, 4 and 5 will give sufficient information to enable the placement of concrete not varying appreciably from the strengths shown in these tabulations.

On important work or on jobs large enough to justify the expense, a careful design of the mix should be made to determine the proper proportions of the materials and the total amount of water to be used. The cement is usually the most expensive ingredient and, therefore, if it is possible to reduce the amount of cement used by adjusting the proportions of the aggregate, producing thereby a leaner mix of equal or greater density and strength, economy is effected, providing the cost of handling this mix is no greater than that of a richer one.

Where it is necessary to make trial batches the following formula, developed by Professor A. J. McGaw of the University of Wyoming, may be found convenient for determination of the cement factor:

$$F = \frac{0.2872 \quad CU}{B}$$

where F = cement factor in sacks of cement per cubic yard of concrete

C = cement in batch in pounds

U = wet unit weight of concrete in pounds per cubic foot

B = weight of batch in pounds

In the various trial mixes the above formula was used during the Wyoming tests and was checked by the Absolute Volume Method. The results obtained by the two methods checked within two per cent in all cases.

CONFIRMATION TESTS

In an attempt to develop information on a subject related to Haydite concrete mix design at the University of Wyoming the opportunity was taken to run check tests in substantiation of the curves developed in Figures 3 and 4 using separate and combination aggregates from different plants as:

1. Kansas City "Fine", Buffalo "Intermediate", San Rafael "Coarse."

2. Danville "Fine", St. Louis "Intermediate", Kansas City "Coarse."

3. South Park "BX."

4. San Rafael "Fine", St. Louis "Intermediate", Buffalo "Intermediate" ("C").

   (The grading of the above separates was as received from the respective plants.)

5. A combination aggregate, which was produced by taking approximately one cubic foot each of Fines and Intermediate and one-half cubic foot of Coarse from the produce of each of

the six United States plants, thoroughly mixing this aggregate and rescreening, retaining as separate portions the amount retained on Tyler standard screens with a ratio of 2 to 1.

These separate portions were recombined as an aggregate having a sieve analysis as follows:

	"B" CUMULATIVE	COMPOSITION OF AGGREGATE PERCENTAGE	POUNDS
Pass .742 opening (3/4)			
Retained on .371 opening (3/8)	17%	17%	13.6
Retained on #4	46%	29%	23.2
Retained on #8	59%	13%	10.4
Retained on #16	68%	9%	7.2
Retained on #28	76%	8%	6.4
Retained on #48	83%	7%	5.6
Retained on #100 Mesh	90%	7%	5.6
Retained on #200 Mesh	98%	8%	6.4
Pass #200 Mesh	2%	2%	1.6
		100%	80.0

Using aggregate combinations 1 to 5, cement content taken from Figure 3 and total water from Figure 4, cylinders were cast for various predetermined strengths, cured and broken at 28-day age. The results from approximately 100 cylinders are platted on the respective figures in the form of a star. In many instances the position of this star on the figure represents individual breaks on eight or more cylinders.

UNIT WEIGHT

To observe the changes in the weight of Haydite concrete after hardening, a series of blocks were made from the same concrete as was used in the cylinders of Series A-2 and A-3, (University of Illinois tests). These blocks were 12" high, 6" wide and 12" long. They were moulded in wooden forms and were tamped in the standard manner of making cylinders. They were left with the top surface exposed for 24 hours, when the forms were removed and the blocks weighed. They were then stored six days in the standard moist room and weighed again. This was followed by three weeks storage in the air of the laboratory and a final weighing.

Figure 6 has been constructed using the weight at the end of the 28-day period as the abscissa and the unit weight of fresh concrete as the ordinate to show the relationship of these two quantities. Further investigations at the University of Illinois reveal that the unit weight of fresh concrete varies slightly in terms of strength and in

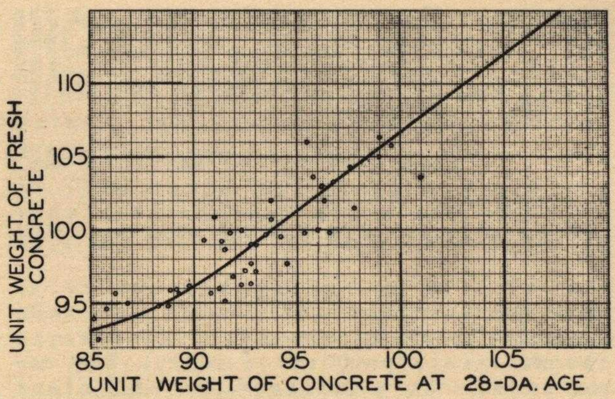


Fig. 6

terms of the ratio of fine aggregate to the total aggregate, but the variation in both the above properties is so small as to be negligible in actual practice. There appears to be a tendency towards an increase in loss of moisture in air storage as the mixes are made leaner and wetter, but these variations are not altogether consistent.

The curve in Figure 7 shows the relationship between the unit weight of fresh concrete and the unit compressive strength at the end of 28 days.

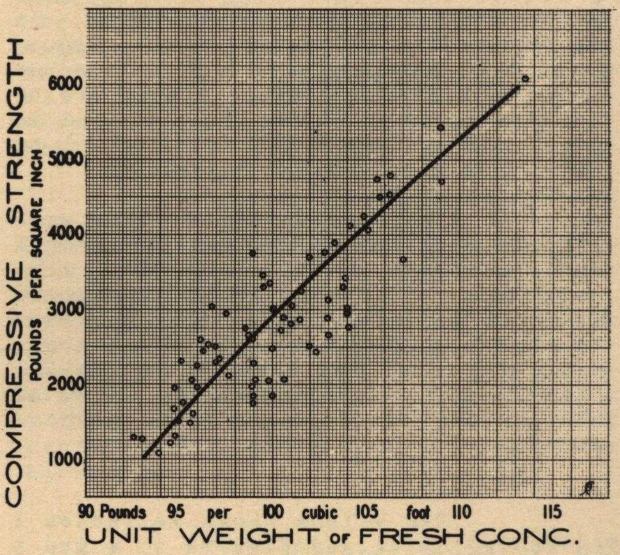


Fig. 7

AGGREGATE GRADING

In the tests at the University of Illinois and the University of Wyoming the grading for the various classifications was accepted as received from the plants with no attempt being made by regrading to make it conform to any definite standard. This grading is shown in Figure 8 which of necessity reflects the average grading of the aggregate received as each lot varied to some slight extent.

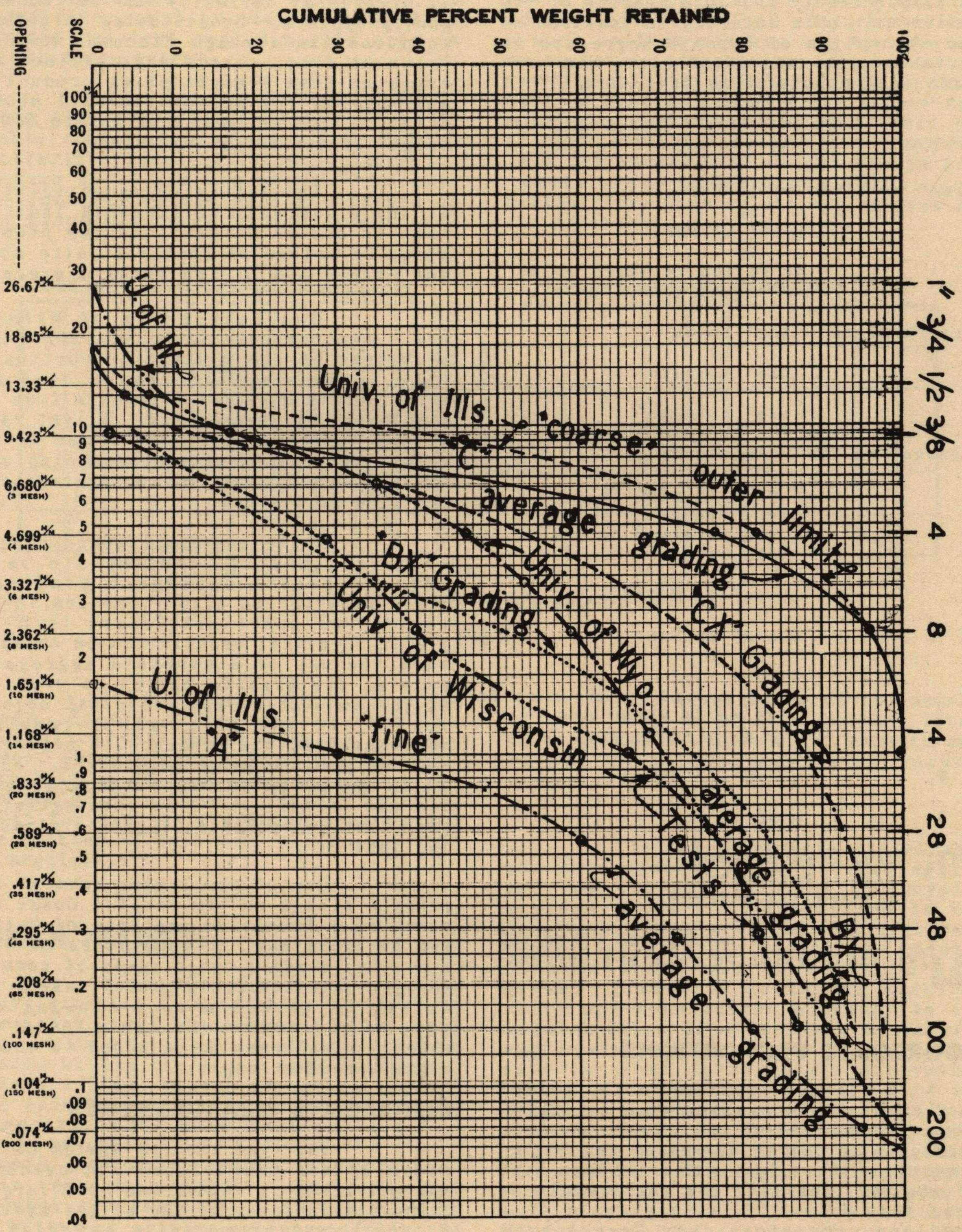

CUMULATIVE PERCENT WEIGHT RETAINED
OPENING
SCALE
0
10
20
30
40
50
60
70
80
90
100%
26.67
18.85
13.33
9.423
6.680 (3 MESH)
4.699 (4 MESH)
3.327 (6 MESH)
2.362 (8 MESH)
1.651 (10 MESH)
1.168 (14 MESH)
.833 (20 MESH)
.589 (28 MESH)
.417 (35 MESH)
.295 (48 MESH)
.208 (65 MESH)
.147 (100 MESH)
.104 (150 MESH)
.074 (200 MESH)
1"
3/4
1/2
3/8
4
8
14
28
48
100
200
U. of W.
Univ. of Ills. "coarse" outer limit
"C"
average grading
Univ. of Wyo.
"BX" Grading
"CX" Grading
Univ. of Wisconsin
U. of Ills. "fine"
"A"
average Tests
average grading
BX grading

Fig. 8

In attempting to duplicate the results of any of the tests it must be borne in mind that the grading cannot vary appreciably from the grading of the individual tests referred to inasmuch as the absorption of Haydite aggregate is variable with individual sizes and possibly with combinations of gradings.

Designations of aggregate at the various plants are approximately:

"Fine" or "A" = #4 to Dust
or
3/16" to Dust
or
8% to 10% retained on #8
to 98% retained on 200

"Intermediate" = 1/2" to #4
or "B"
or
3/8" to 3/16"
or
1/2" to 7/32"

"Coarse" or "C" = 3/4" to #4
or
7/8" to 3/8"
or
10% retained on 3/4"
all retained on 1/2"

CX = 3/4" to Dust

BX = 1/2" to Dust
or
Pass 1/2"
12% to 16% retained on #4
4% to 6% Minus 100
F.M. 3.85 to 4.16

F. F. = 3/8" to Dust

A. A. = #8 to Dust

NOTE: 3/32 = #5 Screen;
3/16 = #4 Screen;
7/32 = #31/2 Screen

It is not considered essential to give the cumulative retained percentages.

AGGREGATE PROPORTIONS

It has long been a recognized fact that as the maximum size of aggregate is increased the ratio of fine aggregate to coarse aggregate can be decreased. Inversely, with a maximum size of 3/4 in. (Haydite) the ratio would be less than if 1-1/2 in. aggregate were used and, therefore, the Gravel-sand (G/s) ratio more nearly approaches 1.0 than would be the case if a larger size were possible. As early as 1918 Duff Abrams set up the mechanics to determine the most economical ratio and while the Fineness Modulus has been found to be demonstrably unsound, and has generally been abandoned it still has a function if arrived at correctly and is intelligently applied. Substituting in Abrams' equation the average Fineness Modulus value of fine, coarse and combined aggregates from present plant production and solving for percentage will show a ratio of fine to coarse of 52% to 60% by weight or 44% to 53% by volume.

The extensive investigations at the University of Illinois indicate that to secure workability the proportions by volume of coarse Haydite shall not exceed 55% of the total aggregate.

The University of Wyoming tests conclusively show that about 50% by weight is the minimum proportion of fine aggregate that can be used and still obtain a satisfactory mix from the standpoint of workability. Slight variations in these percentages can be obtained by trial mixtures depending upon the moisture content of the aggregate at the time of its use.

While aggregate quantity figures in Table III contemplate using three separate aggregate gradings, i.e., Fine (0" to 3/16"), Medium (3/16" to 1/2" or 5/8") and Coarse (5/8" to 3/4"), identical results can be obtained thru the use of a combined aggregate, such as the grading BX (0" to 5/8") or AX (0" to 3/4"). The principal objection to the use of a "plant-combined aggregate" is the tendency to segregate when shipped in large quantities. Where it is possible to batch the aggregate its use is believed even more satisfactory than re-combining separate sizes on the job.

One of the larger natural aggregate plants on the Pacific Coast has promoted a lucrative practice of batching by truck haul in quantities of 1/2, 1, 1-1/2, 2 and 4 cubic yards of combined aggregate correctly graded, where the driver is handed a card showing the amount of cement, in sacks, and the water, in gallons, to be added to obtain a guaranteed strength.

AGGREGATE MEASUREMENTS

The time honored system of expressing mix proportions and batching the materials by volume has been largely discarded in favor of the weight system. A cubic yard of granular material in general and of concrete aggregate in particular is an indefinite quantity. Any amount of moisture tends to increase the volume of Haydite aggregate so that the term "cubic yard moist" or "cubic

foot moist" can be duplicated with that particular aggregate only at the time it contains a like amount of moisture. A ton of aggregate, on the other hand, is a definite quantity and for precision usually requires qualification only as to moisture content.

The use of a "loose damp" cubic foot measurement leads to considerable variation in yield. This is particularly evident in the quantities for masonry units and was exemplified more particularly in the yields obtained in the Wisconsin tests in comparison with those obtained by various block manufacturers, the variance in some cases being as extreme as eight blocks per cubic yard. It is quite likely that for comparative yields and comparative data a more uniform measure may be obtained by accepting the aggregate in its "plant condition" and obtaining the "rodded unit" weight of the material rather than accepting the rules of measurement applicable to natural aggregate concrete. This dry rodded unit weight should contemplate the material in "plant condition" form with no attempt to oven dry the material.

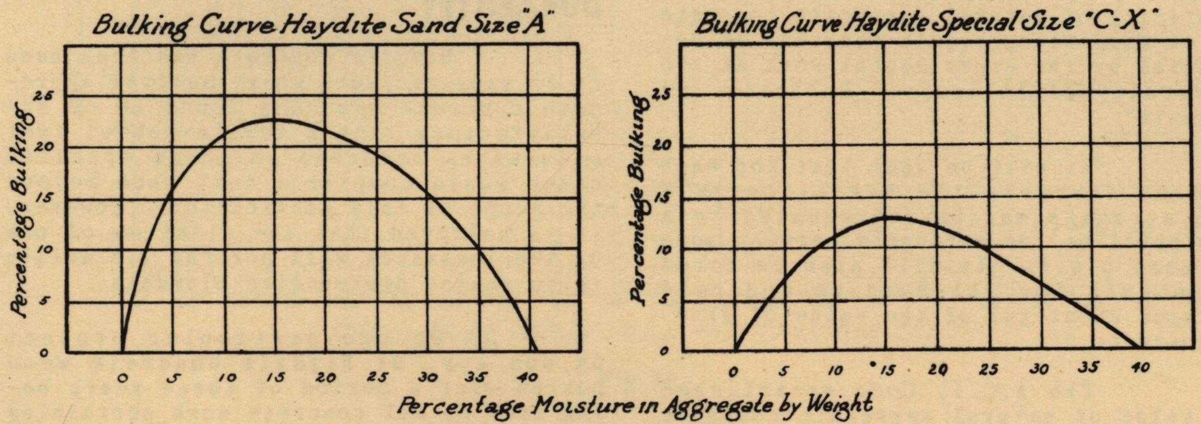


Fig. 9

When aggregate is measured loose, Figure 9, (extracted from the Hydraulic-Press Brick Company literature), shows curves giving the approximate bulking of both Haydite, sand size, "A" and Haydite Special, coarse to fine, "C-X" for various percentages of water. The bulking of Haydite, coarse size, "C" is negligible.

DESIGN FEATURES

Haydite being a chemically inert material does not have any properties that would contribute to the rusting of reinforcing steel or conduits placed within the mass, and, therefore, offers a light weight structural material eliminating the destructive properties that have been present in other light weights. In addition to these highly desirable factors it has a certain tenacity, probably due to its low modulus of elasticity, that enables it to withstand weathering successfully and to resist more successfully stresses not anticipated in design. This feature has been evidenced in many structures that have successfully withstood foundation erosion and "ground slips."

The lower value of the modulus of elasticity of Haydite concrete introduces a higher value of "n" than is used in the structural design of natural aggregate concrete.

In the University of Illinois series a control using natural aggregate was run parallel with All-Haydite aggregate tests. In addition to the compression tests of the 162 cylinders comprising a single series the modulus of elasticity was recorded on each break. From this series of moduli a curve was constructed showing the initial modulus of elasticity of natural aggregate concrete. By platting the data in other forms it was determined that for deformations up to 50% of the ultimate deformation, the relations of secant moduli of Haydite and gravel concretes are essentially the same as those of initial moduli. It was further concluded that the primary difference in deformation is the difference in elastic deformation (deformation up to the line for initial modulus) as indicated by the ratio 55%, and that the difference in plastic deformations (remaining deformations) is slight and of secondary importance.

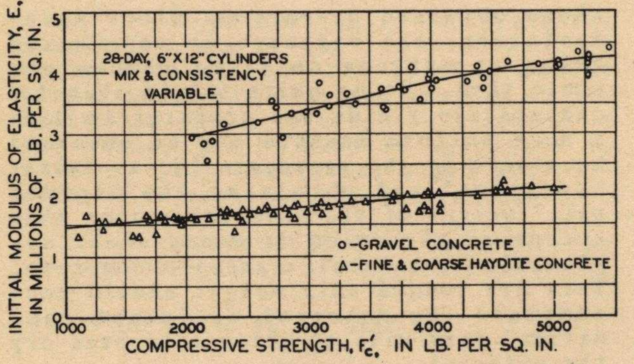


Fig. 10

Figure 10 shows the modulus of elasticity of natural aggregate concrete and of Haydite aggregate concrete as determined by the experimental work at the University of Illinois. Bulletin 237 comments:

"It will be seen that for each kind of concrete the variation in E with strength may be represented by a straight line for strengths between 2000 and 4000 p.s.i. It will also be noted the moduli for All-Haydite concrete averages about 55% of the value of gravel concrete."

The A.C.I. Code established the value of natural aggregate concrete as 1000 f'_c. For Haydite concrete the experimental work would indicate that 550 f'_c would be a satisfactory value. In the design of reinforced concrete the actual modulus of elasticity obtained in this series of tests more nearly reflects correct design procedure than the use of any other values.

Table V is reproduced from "Construction and Design Features of Haydite Concrete", Richart and Jensen, A.C.I. Proc. Vol. 27, giving the design properties for both values of the modulus of elasticity.

An important factor in the design of rectangular reinforced concrete beams is the weight of the beam which may vary from 15% to 40% of the superimposed load that will come on the beam.

Figures 11 to 14 inclusive show the percentages of dead load to live load for both natural aggregate concrete and Haydite concrete beams for various lengths, and live loads, using both the Experimental value and the Code value, for the modulus of elasticity of Haydite concrete.

DURABILITY

Haydite concrete has been used in so many projects where natural aggregate concrete has been found to be unsatisfactory that a tabulation of test endurances recorded in these specific cases would compile a text much beyond the scope of this publication. However, it is believed that the citation of one or two instances will portray its ability to resist destructive elements.

On one particular project 65,000 c.y. of Haydite concrete were poured over a period of three years being used on all concrete work pertaining to Industrial Development, municipal, sewerage, water works, and appurtenant plant design. An inspection of the work thirteen years later revealed that in all cases the Haydite concrete was still functioning to the full extent of the design. On this project, sidewalk, pavement and floor slabs were constructed using concrete of approximately 1700 to 1900 p.s.i. at 28-day age in a country subject to a temperature variation of 153° and after a period of thirteen years of weathering were found to be entirely satisfactory.

BALANCED REINFORCEMENT, f_s 20,000 LB. P.S.I.; f_c 0.40 f'_c

PROPERTY	E_A EXP. VALUES				E_A 550 f'_c			
f'_c	2000	2500	3000	3750	2000	2500	3000	3750
f_c	800	1000	1200	1500	800	1000	1200	1500
n	18.4	17.1	16.0	14.5	27	21.8	18.2	14.5
k	0.423	0.461	0.490	0.520	0.521	0.521	0.521	0.521
j	0.859	0.846	0.837	0.827	0.826	0.826	0.826	0.826
p	0.0085	0.0115	0.0147	0.0195	0.0104	0.0130	0.0156	0.0195
K	145	195	245	322	172	215	258	323

Table V

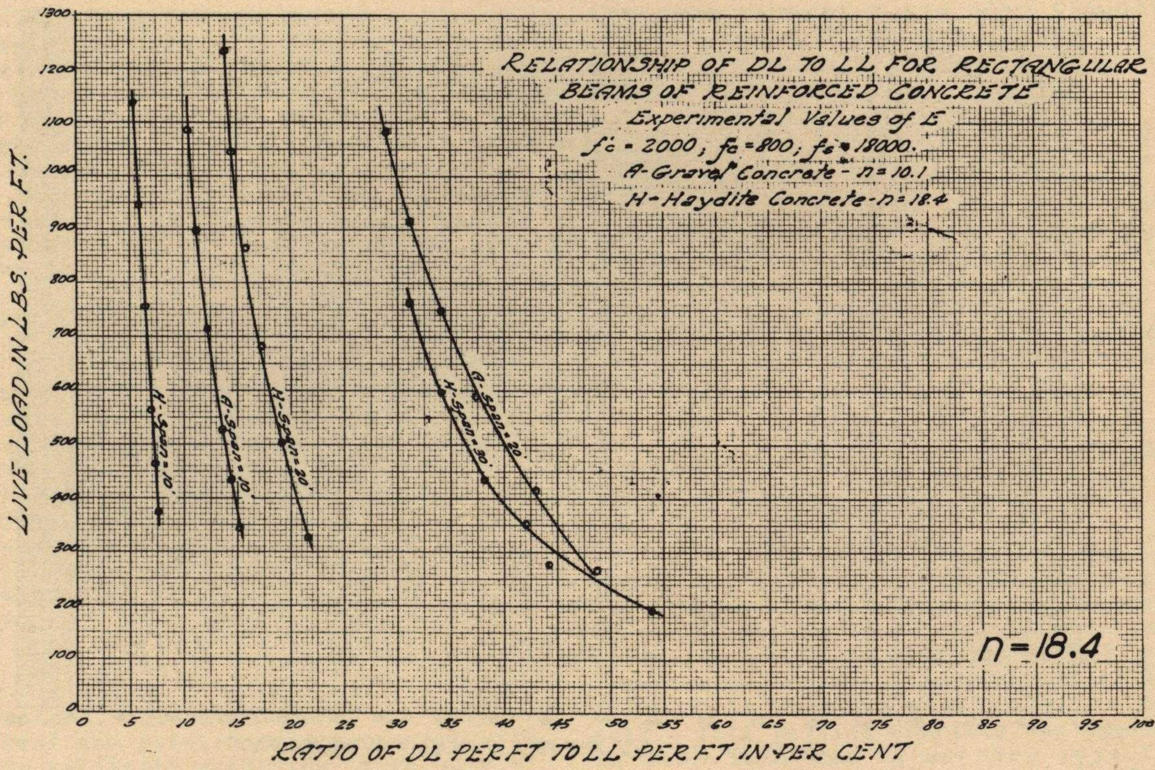

RELATIONSHIP OF DL TO LL FOR RECTANGULAR
BEAMS OF REINFORCED CONCRETE
Experimental Values of E
f'c = 2000; fc = 800; fs = 18000.
A-Gravel Concrete - n = 10.1
H-Haydite Concrete - n = 18.4
n = 18.4
LIVE LOAD IN LBS. PER FT.
RATIO OF DL PER FT TO LL PER FT IN PER CENT
H-Span = 10'
A-Span = 10'
H-Span = 20'
A-Span = 20'
H-Span = 20'
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig. 11

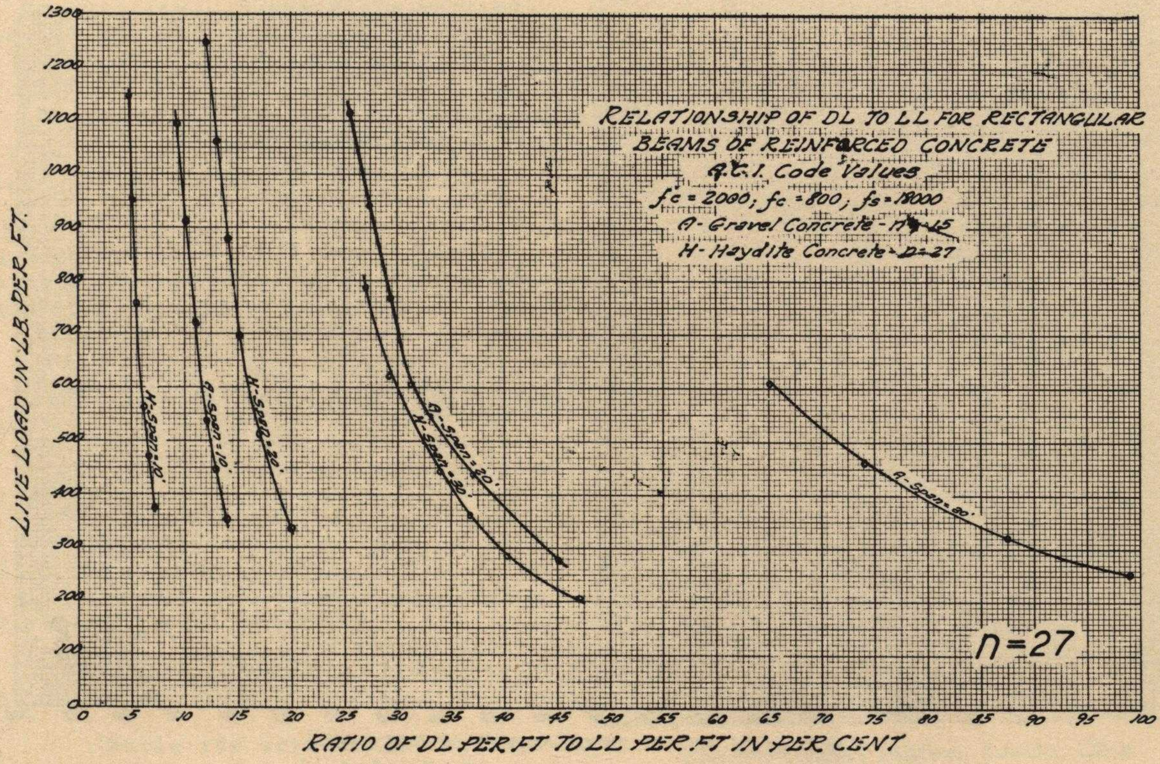

RELATIONSHIP OF DL TO LL FOR RECTANGULAR
BEAMS OF REINFORCED CONCRETE
A.C.I. Code Values
f'c = 2000; fc = 800; fs = 18000
A-Gravel Concrete - n = 15
H-Haydite Concrete - n = 27
n = 27
LIVE LOAD IN LB PER FT.
RATIO OF DL PER FT TO LL PER FT IN PER CENT
H-Span = 10'
A-Span = 10'
H-Span = 20'
A-Span = 20'
H-Span = 20'
A-Span = 20'
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig. 12

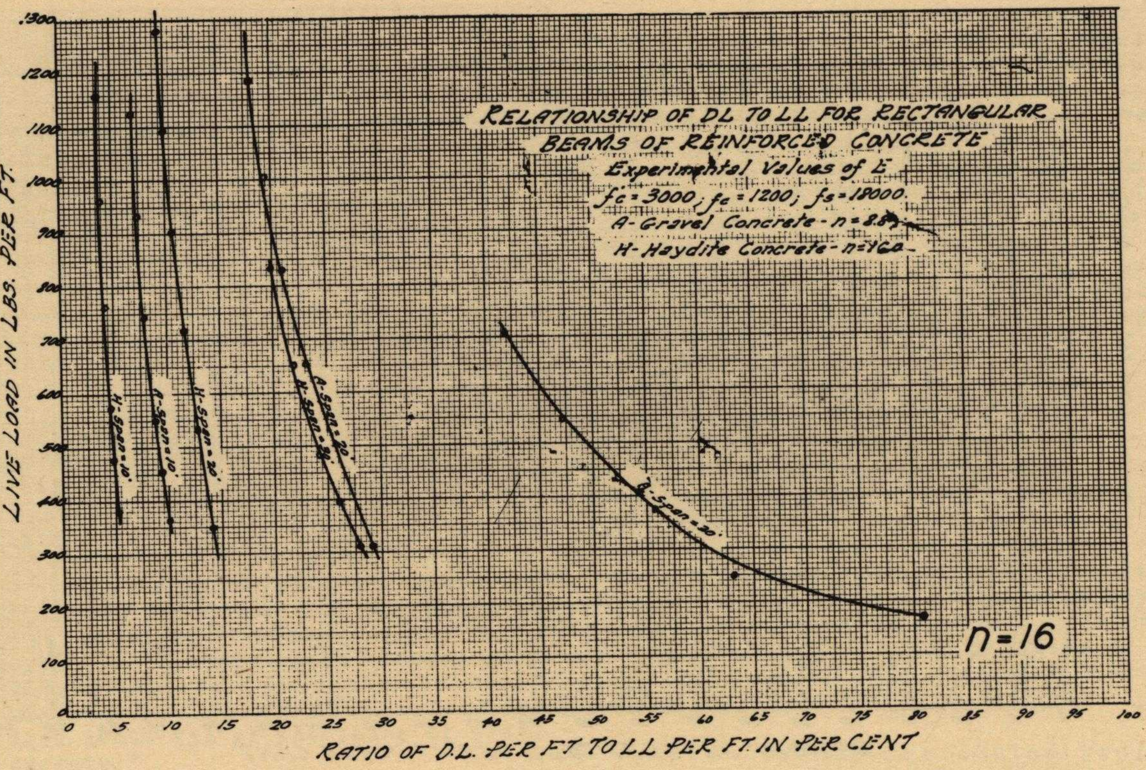

RELATIONSHIP OF DL TO LL FOR RECTANGULAR
BEAMS OF REINFORCED CONCRETE
Experimental Values of E
fc = 3000; fc = 1200; fs = 18000.
A-Gravel Concrete
H-Haydite Concrete
n=16
LIVE LOAD IN LBS. PER FT.
RATIO OF D.L. PER FT TO L.L. PER FT. IN PER CENT
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig. 13

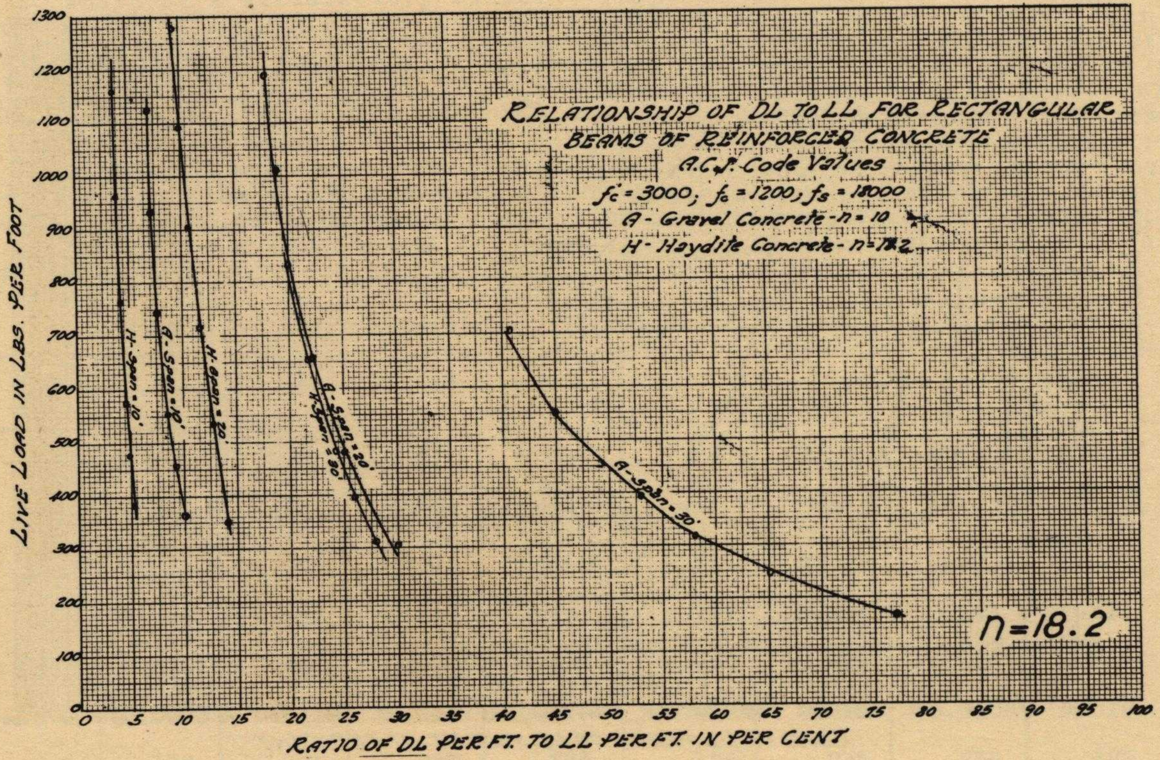

RELATIONSHIP OF DL TO LL FOR RECTANGULAR
BEAMS OF REINFORCED CONCRETE
A.C.I. Code Values
f'c = 3000; fc = 1200; fs = 18000
A - Gravel Concrete - n = 10
H- Haydite Concrete
n=18.2
LIVE LOAD IN LBS. PER FOOT
RATIO OF DL PER FT. TO LL PER FT. IN PER CENT
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

Fig. 14

Duff Abrams in his early investigation concluded that concrete to resist weathering action successfully must have a compressive strength of 3500 p.s.i. at a 28-day age. Undoubtedly the properties of the aggregate permit Haydite concrete of a lower strength than that recommended for natural aggregate concrete to resist weathering action successfully. Substantiation of this may be found also by reviewing the University of Wisconsin tests (A.C.I. Journal Nov. 1939).

The Robert W. Hunt Company was employed by the Western Brick Company to conduct a series of tests to determine the resistance of Haydite concrete to locomotive gas fumes. They made six 12"x12"x2-1/2" slabs using Haydite concrete and the same number of slabs, same size, using sand and limestone aggregate. These slabs were cured for twenty-eight days in the air. At the end of the 28-day curing one Haydite concrete slab and one Limestone concrete slab were placed in the exhaust hood of sulphurous fumes of the Hunt Company's laboratory; the second pair was left on the roof and painted once each week with dilute sulphuric acid; the third pair of slabs was suspended in the smoke jack of the Chicago, Burlington & Quincy Railroad Company's roundhouse; the fourth pair of slabs was suspended in the quenching station of the By-Products Coke Corporation. These slabs were exposed to the above mentioned conditions for a period of four months at which time they report:

"The specimens indicated that the four (4) months exposure to concentrated sulphurous fumes, dilute sulphuric acid, constant action of locomotive smoke and action of steam from the quenching of coke, which contains some sulphuric acid, showed no effect on the reinforcing or concrete in either case."

The test was continued and at the end of twenty-six months they reported:

"Slabs Exposed to Sulphuric Acid Fumes:

The Haydite slab does not seem to have been effected in any way while the surface of the Limestone slab indicates considerable bleaching.

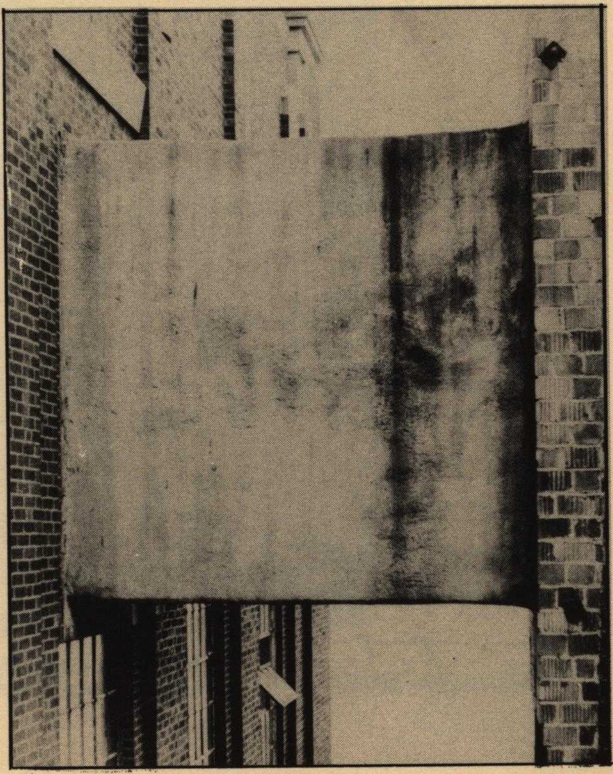
Slabs Painted with Dilute Sulphuric Acid:

While the surface of the Haydite slab seems to be slightly dusty the surface of the Limestone slab seems to have been bleached to such an extent that the numeral 7 and also the date 2-10 which were inscribed on it to a depth of about 1/8" have been entirely removed due to the weathering.

The conclusion at this time seems to be that the Haydite concrete even though it may have been abused by the sulphuric fumes or dilute sulphuric acid, does not appear to be affected or, rather, weakened, after further exposing the specimens to weathering for 26 months. The Limestone concrete seems to be weakened by this test and when exposed to weathering, the weakness showed up."

In the reconstruction of the breeching at the Elyria Pumping Station, Lorain, Ohio, some endurable type of protection was necessary.

Haydite concrete was applied by the Gunite process while the plant was in full operation, a one inch covering being applied for insulation followed by an additional four inches for structural purposes. Temperature at the time of insulation was approximately 400°. This Haydite concrete was applied in July 1932 and in October 1939 the breeching was carefully inspected, showing no cracks in any part of the insulation.



Elyria Pumping Station, Lorain, Ohio
View showing breeching
with relation to buildings

While not strictly related to durability, the tenacious character of the aggregate, as represented by the McIntyre article, seems pertinent to a discussion of the Resistant properties of Haydite aggregate concrete.

Quoting from the ENR, November 10, 1921:

"Mr. McIntyre states that his attention was called to Haydite about a year ago (1920), when he was designing a twelve-story reinforced-concrete building. The manufacturers desired to have it used on the building, but owing to the fact that it was an unfamiliar material to the engineer and that there were little data available at that time regarding its merits he did not feel justified in permitting its use. It interested him so, however, that he conducted several experiments with it and has been continuing his investigations in regard to the strength of the concrete made from it and to its economic relations to concrete building."

While the method of testing was somewhat crude the behavior of the material, as reflected in Figure 15 reproduced from the article, reflects the behavior of Haydite concrete under load. The total load for this maximum deflection was 960 pounds per sq. ft., giving a calculated stress to the concrete at 7-months age of 3075 p.s.i. The action of this single test specimen evidenced at the very beginning of Haydite concrete design a property of the material which in many cases has been proven in subsequent designs.

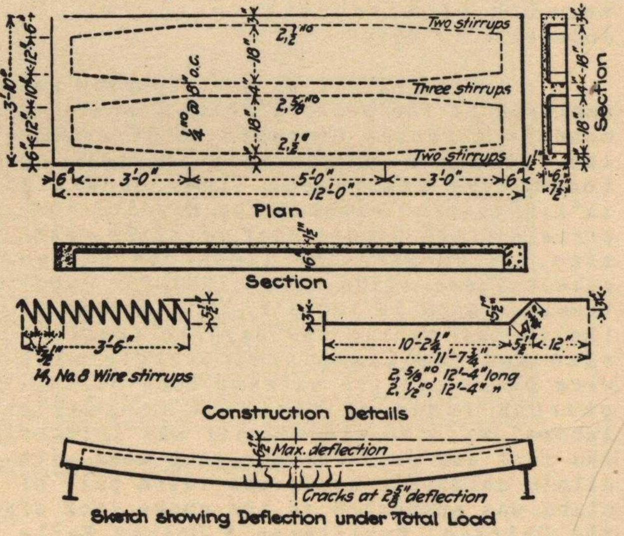
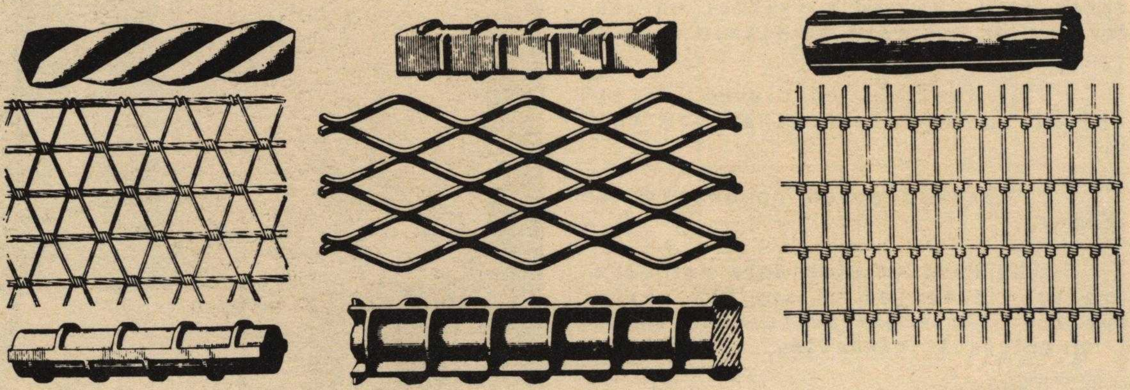


Fig. 15

The Cheapest Concrete Insurance



Monolithic Haydite Concrete Construction
Southern California

ARMOUR TESTS

Work with the Atlas Lumnite Cement Company towards the development of a refractory concrete resulted in a number of successful installations but evidenced a need for experimental data on the fire resistant properties of Lumnite-Haydite concrete.

In the early part of 1936 the American Aggregate Company in cooperation with the Haydite Manufacturers Association initiated a series of tests to be conducted at the Armour Institute of Technology under the personal supervision of Professor Phil C. Huntley, a member of the faculty and a recognized testing engineer. Results of these tests were reported by Professor Huntley under dates of July 17, 1936, September 17, 1936 and July 13, 1937 and are summarized in the following data:

In a test using Pittsburgh Haydite and Lumnite Cement, Professor Huntley reports:

"The rodded dry Haydite weighed 70 pounds per cubic foot. This was wet and let stand for 14 hours, and weighed 85.2 pounds. The Haydite then contained 15.2 pounds of water. This damp Haydite was then thoroughly mixed with 23-1/2 pounds of Lumnite Cement (mix 1 to 4) using an additional 7 pounds of water; slump 1"."

The material was cast as 2x4" cylinders, for the Compression test, and let stand in molds, then immersed in water for 24 hours, then dried to 350°F. for 5 hours and "sets of 5 each were then heated to temperatures noted and tested", the cylinders being held in the indicated heat for a period of 5 hours. The average strength value of each set at its tested temperature is shown graphically in Figure 16, designated Armour H_1.

Tests were conducted using aggregate from both the Danville and the Pittsburgh plant and are reported:

"The Haydite was rodded dry, weighed, wet down, and let stand for 14 hours, at which time it was reweighed to determine the percent of contained moisture. This procedure was the same for all tests.

"The mix was 1 to 4, and 1 to 6 by volume, using both kinds of Haydite. Mixed so as to give a 1" slump. Cast in 2x4" molds and let stand for 24 hours, removed and placed in water for 32 hours, then in air for 20 hours and dried at 350° Fahr. for 5 hours.

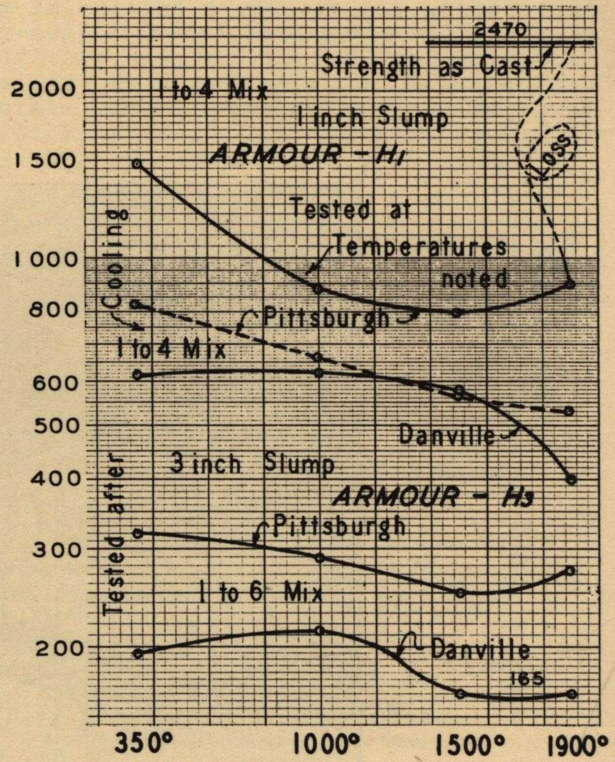


Fig. 16

"Five were then heated to the temperature noted and held for 5 hours, let cool slowly, capped with plaster of paris, and tested."

Average compressive strength for each group (consisting of five cylinders for each temperature) and for the three complete mixes at temperatures of 1000° to 1900° is shown in Figure 17, with the designation H_2.

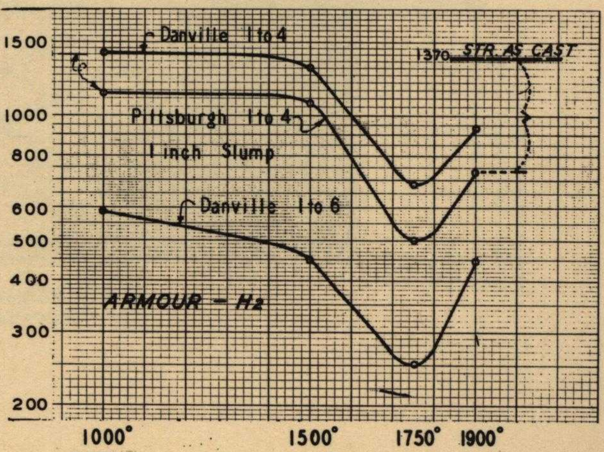


Fig. 17

A third test, at temperatures from 350° to 1900°, platted in Figure 16, designation Armour H_3, is reported as:

"The mix was 1 to 4, and 1 to 6 by volume, using both kinds of Haydite. Haydite was wet and let stand for 14 hours. Then mixed so as to give a 3" slump.

"Cylinders left in molds nine hours, removed and placed in water 24 hours, then in air for 15 hours, dried at 350°F for five hours. Five of each mix were then heated to temperature noted and held for five hours, let cool slowly, capped with plaster of paris, and tested."

In the tests referred to as Armour H_1, in which the concrete was tested "at" the noted temperature (hot) there appears to be a minimum strength value at 1500° and an increase in strength from this point to the 1900° point. This "regained strength" is apparent in only one mix (Pittsburgh 1 to 6) in Armour H_3 Series, using the same type of aggregate, with the same mix, except with a three inch slump consistency, and "broken after cooling."

Series Armour H_2 shows a distinct gain of strength between 1750° and 1900°, and in one test, where a compressive strength of the cold (unheated) cylinder was obtained, the relation between "regained strength" at 1900° and its cold strength is evidenced. Unfortunately, there appears to have been no cold (unheated) strength obtained for the combinations shown as H_2 and H_3 other than that of the one combination.

There is a common belief that Haydite-Lumnite concrete shows a continual decrease in compressive strength, if the strength is determined while the cylinder is at the comparative temperature, until it reaches a point commonly termed the "twilight zone" and that from this point it has a certain increase in compressive strength as the temperature is increased. Further, that if the compressive strength is determined after the cylinder has been allowed to cool a curve of similar form could be constructed from the cold compressive strengths (after heating) and that a point on the curve whose abscissa is a temperature approximating 2000°, will have an ordinate coinciding with the cold (before heating) compressive strength.

The generally accepted theory of refractory concrete strength is that as heat is applied to the mass there is a gradual breaking down of the "hydraulic" bond causing a decrease in strength and reaching a minimum somewhere at or between 1200° and 1600°, depending upon the type of cement used, and termed the "twilight zone." As the heat is increased beyond these temperatures the bond assumes a "ceramic" form and the strength increases. The percentage ratio of this regained strength to the original strength seems so far to be indeterminate.

Professor Huntley describes this transition as:

"A so-called 'Ceramic Bond' is developed by the concrete when subjected to heat that is near the fusion point of the aggregate. The name seems to be something of a misnomer but since that is what it has been called it will have to serve. What is meant by this is that the surface of the concrete exposed to the heat is fused to varying depths depending upon the heat. That this actually takes place is very definitely shown in the tests set forth in this report.

* * * * * * * * *

"'Ceramic Bond', the so-called fusion of the exposed surface, would increase the strength of the sample if it was permitted to cool and the slightly melted surface solidify. The increase in strength would be caused by the harder fused part of the sample. Blisters on the face of the test block indicate this state of fusion which would tend to lessen the crushing strength of the sample if tested hot. Thus, by testing under heat, it was possible to avoid any additional strength which would have resulted on cooling."

That portion of the Huntley tests reacting in accordance with the theory show a regain of strength at or near the 1750° point which does not confirm the point of transition in the foregoing quotation.

Fusion point for the various aggregates was obtained as follows:

Kansas City	2210° F.
East St. Louis	2270° F.
Cleveland	2250° F.
Buffalo	2280° F.
Danville	2250° F.
Pittsburgh	2270° F.

Cones were formed, using a proportion of one part Lumnite cement to four parts Haydite by volume, similar in shape to the Standard Seger cones, and on test, fusion started when Seger cone No. 9 melted, or at a temperature of 2392° F.

From the Huntley tests it seems evident that at the low point of compressive strength the material does possess structural qualities. The lowest point of his series of curves, reached at a temperature of approximately 1750°, shows sufficient structural strength to enable the material to support some loading.

A Heat Transmission, Heat Gradient, Heat Conductivity and Coefficient of Expansion determination was run concurrently with the Compression tests.

HEAT TRANSMISSION TEST

The 14x14x2" samples had placed in them, when cast, a series of thermal couples. These thermal couples were spaced 1/4" apart across the 2" depth of the piece. The 14x14" space was exposed to the heat and the factor K calculated from the data thus taken.

The units of the factor, K (B.T.U./sq.ft./inch thickness/ degree difference in temperature/hour) from the results of a typical run were as follows:

1.	K	0.644
2.	K	1.085
3.	K	1.864
4.	K	2.210
5.	K	2.880
6.	K	2.935
7.	K	3.235
8.	K	3.310

These numbers from 1 to 8 represent the K values between the first and second, the second and third, third and fourth, etc., thermal couples thru the piece from the heated side to the cool side.

K values were calculated from the following formula:

$$K = \frac{2\ W\ (T)\ (4)\ (t)}{t_1 - t_2}$$

where W weight of water / run (in#)
T temperature difference of inlet and outlet water, in degrees F.
t thickness of piece
t_1 maximum temperature, hot side
t_2 minimum temperature, cool side

HEAT GRADIENT THROUGH 2" THICK SLAB

Cold Side		200 degrees F.
0.1"	in from surface	554 degrees F.
0.2"	in from surface	616 degrees F.
0.5"	in from surface	794 degrees F.
0.75"	in from surface	944 degrees F.
1.12"	in from surface	1072 degrees F.
1.35"	in from surface	1202 degrees F.
1.60"	in from surface	1275 degrees F.
2.0"	in from surface	1507 degrees F.

A computed mean temperature of 865° F

HEAT CONDUCTIVITY TEST

Temp., Hot & Cold Sides:	547-253	845-355	1154-446	1157-543	1720-680	1906-894
Temp. Mean:	400	600	800	1000	1200	1400
"K" Factor:	3.15	3.25	3.40	3.47	3.55	3.57

COEFFICIENT OF EXPANSION TEST

Temperature Range, in degrees Fahrenheit	Coefficient of Expansion in inches per degree F., per inch, length
100-400	0.0000024
400-700	0.0000036
700-1400	0.0000041

Cumulative percentage grading of the combined aggregate used in this test is shown in Figure 18.

ALFRED TESTS

Tests conducted at the New York State College of Ceramics, Alfred, New York, under the personal direction of Mr. Frank E. Lobaugh, were presented as the paper "Investigation of Certain Properties of Refractory Concrete" by R. T. Giles at the Forty-first Annual meeting of the American Ceramic Society, Chicago, Illinois, April 18, 1939 and published in the Bulletin of that Society, (Vol. 18, No. 9), Sept. 1939, from which only that portion of the investigations and results as pertains to the material Haydite has been extracted.

The cement is termed by the authors "Calcium Aluminate." The aggregate (Haydite) was combined in the proportions of one part of coarse aggregate to 1.16 parts of fine aggregate. The coarse aggregate graded from 14.2% retained on #4 to 5.4% retained on #10 and the fine from 3.7% retained on #8 to 24.8% passing #80. The cumulative percentage grading of the combined aggregate is shown in Figure 18.

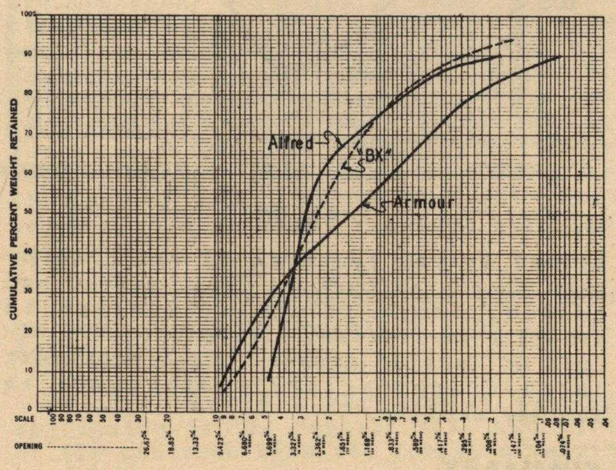


Fig. 18

The aggregate was soaked in water over night before mixing with cement the next day and the proportions used for the test specimens were one bag of cement to four cubic feet of aggregate. The concrete was cast in 2x2" cubes for the Compression test and in 2x2x6" beams for the Flexural test. The specimens were cured in moist air for 24 hours, dried at 120° F. and ground to size before they were placed in the furnace.

Tests were conducted for both compressive and flexural strengths, at temperatures of 1000°, 1500°, 1750° and 2000°, each heat series being maintained on individual cylinders for periods varying from one to twelve days.

The method of firing, as stated by the author, was:

"Firing Procedure: The furnace was brought up to test temperature in 12 hours; 24 hours after the furnace reached the test temperature. 3 beams and 3 cubes of each mix were withdrawn and were reported as the 1-day test. Forty-eight hours after the furnace reached the test temperature, specimens were withdrawn, tested, and reported as the 2-day test. The same procedure was followed for the other time periods. The test period for 1000°, 1250°, 1500° F. continued for 12 days; for 1750° and 2000°F. the test period continued for 6 days."

The individual strength tests have been platted in their temperature group in the relation, "strength" to "days in fire". Figure 19 shows the result of the Compressive test and Figure 20 the result in Flexural strength. From this graphical representation it seems evident that the time of firing in days has no relation to the loss of strength in specimens. An erratic variation from the median occurs in all

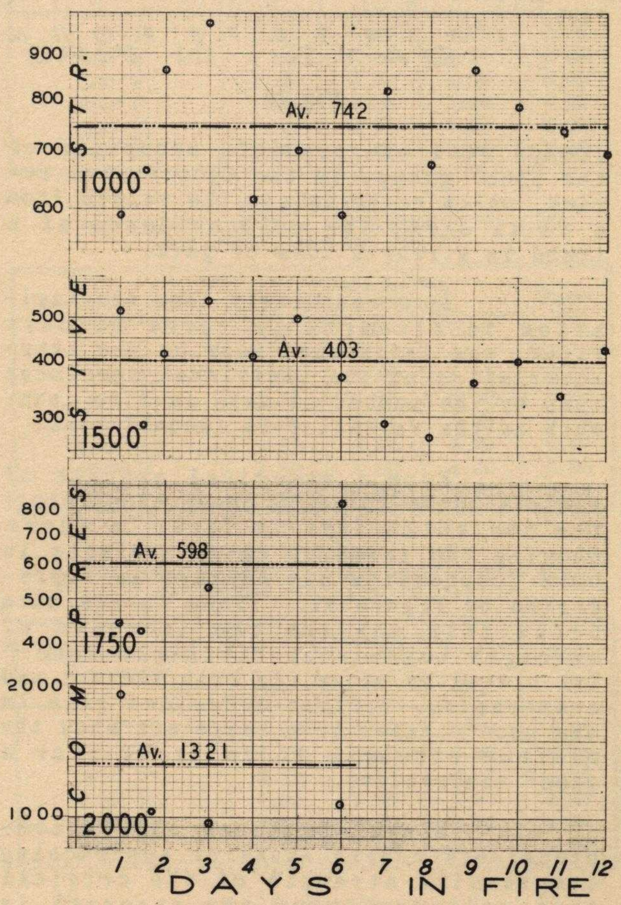


Fig. 19

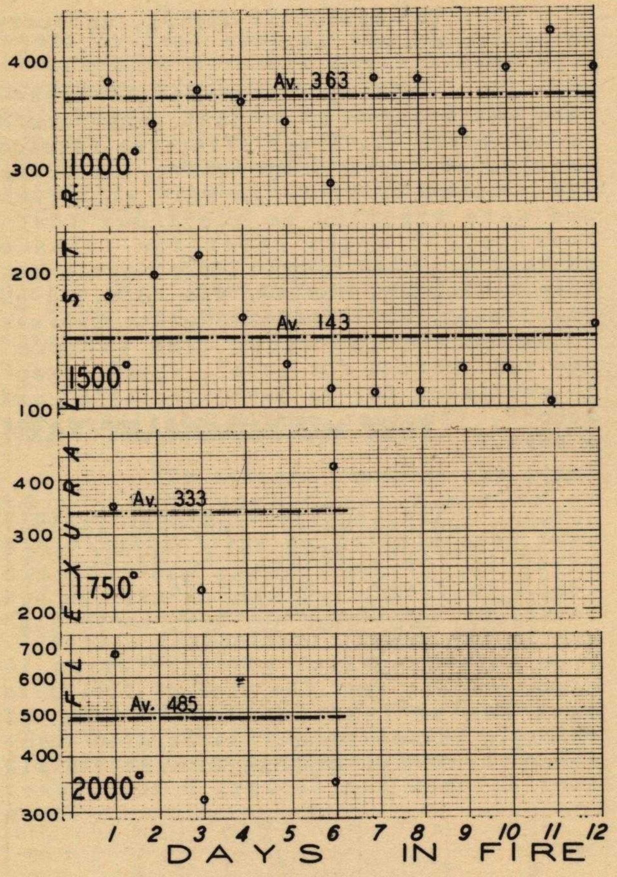


Fig. 20

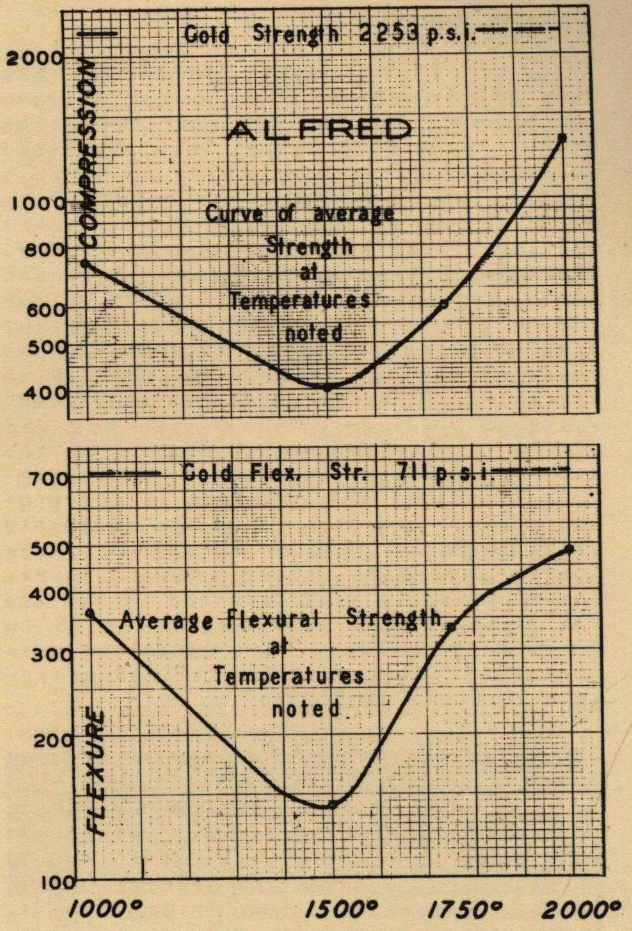


Fig. 21

groups with the possible exception of the 1000° group, in the Compressive series, which reflects, in the values from 9 to 12 days, the only evidence of a trend in strength loss or gain.

It seems likely that the variation in strength in terms of days fired, was influenced more by the characteristics of the individual specimens than by the number of days in fire inasmuch as the variation is inconsistent.

From a numerical average of the strengths for each group (1000 etc.) for the total days in fire, a curve showing the trend of these averages in both Compression and Flexure is represented by Figure 21. These curves more definitely confirm the increase of strength beyond the "twilight zone." The strengths shown, in both flexure and compression, reflect a decided gain in the 2000° temperature range and show the minimum strength to be at or near a 1500° temperature.

Where specimens show a compressive strength equal or approaching compressive strength of the original cast cylinder, when the strength is determined after the cylinder has been heated to the temperature range at or near 2000°, allowed to cool, capped and tested, there is an inclination to assign this regained strength to the effect of "shell" stress. This phenomena is more appropriately discussed in another section.

SUMMARY

A careful review of the test data indicates that there is a wide latitude for further investigations. While all the tests are conformable, the variation in strengths thru firing seems to indicate a possibility that the initial strength of the specimen is not the controlling factor in its strength after firing. It is quite likely that the cement-aggregate combination and aggregate grading as well plays a more important part than does the initial compressive strength.

Haydite-Lumnite concrete has been used in refractory work in refinery installations throughout the world and so far no unsatisfactory behavior has been evidenced. In many refinery installations the material has performed

so satisfactorily that it is with difficulty that any history of its behavior can be obtained. Even accepting this disparity of data.

The following extract from the Amer. Cer. Soc. paper supports the experiments of Professor Huntley as to the failure point:

"The standard load test shows that refractory concrete, using several percentages of cement and various aggregates, will begin to fail at 2250° to 2300. F, and complete collapse will occur between 2450° and 2700° F. This is due undoubtedly to the liquid phase developed as the fusion point of the cement is reached."

Mr. W. E. Barney, manager of the Hydraulic-Press Brick Company's plant at South Park, Ohio, has experimented with refractory Haydite concrete from the beginning of its use. His following comments are pertinent:

"While it is true that at 2000 to 2200 degrees F. our structural values are virtually destroyed as this is about the fusing point of the aggregate, this would be the case only if subjected to a soaking heat of that degree. However, due to the nature of Haydite, which has been demonstrated in many cases, and in actual service, the temperature can be applied to one side and bring it up to the melting point, but it does not penetrate more than about 1/4-inch into the body."

His conclusions are supported by the following quotation from A.C.S. Bulletin:

"Using structurally strong aggregates in the regular mix, the part of the concrete with the lowest strength would have a compressive strength of about 400 lb. per sq. in. and a flexural strength of about 100 lb. per sq. in. The concrete, when exposed to high temperatures on one side only, would vary in strength from the low of 400 to about 1500 lb. per sq. in. on the cold face; on the hot face, the strength would vary with the temperature of exposure and the materials used from no structural strength above 2250°F to as high as 1200 to 1500 lb. per sq. in. for that part of the concrete between 1500° and 2250°F.

"Assuming that a wall is exposed to 2000°F on one side and to atmospheric temperatures on the other, the concrete on the inside and outside will have relatively high structural strength and that of the concrete in the middle of the wall will be much lower; the minimum strengths is approximately the same whether large or small specimens are used."

Mr. W. E. Barney edited a publication for the Hydraulic-Press Brick Company from which Table VI, showing the values of "r" and "K" for Haydite-Lumnite concrete has been extracted.

MIX BY VOLUME
1 PART LUMNITE CEMENT, 4 PARTS HAYDITE "BX-4.00"
UNIT WEIGHT, 88.0 LBS. CU. FT.

Maintained Inside Temperature	"r" Value for Wall Thickness Shown			Factor "K"
	4½"	9"	13½"	
75° F.	1.45	2.90	4.35	3.13
400° F.	1.40	2.80	4.20	3.24
800° F.	1.32	2.65	3.97	3.38
1200° F.	1.28	2.55	3.83	3.52
1600° F.	1.22	2.45	3.67	3.66
2000° F.	1.18	2.35	3.53	3.80

MIX BY VOLUME
1 PART LUMNITE CEMENT, 5 PARTS HAYDITE "BX-4.00"
UNIT WEIGHT, 82.0 LBS. CU. FT.

Maintained Inside Temperature	"r" Value for Wall Thickness Shown			Factor "K"
	4½"	9"	13½"	
75° F.	1.60	3.20	4.80	2.82
400° F.	1.52	3.05	4.57	2.93
800° F.	1.46	2.93	4.39	3.06
1200° F.	1.40	2.80	4.20	3.20
1600° F.	1.35	2.70	4.05	3.33
2000° F.	1.30	2.60	3.90	3.46

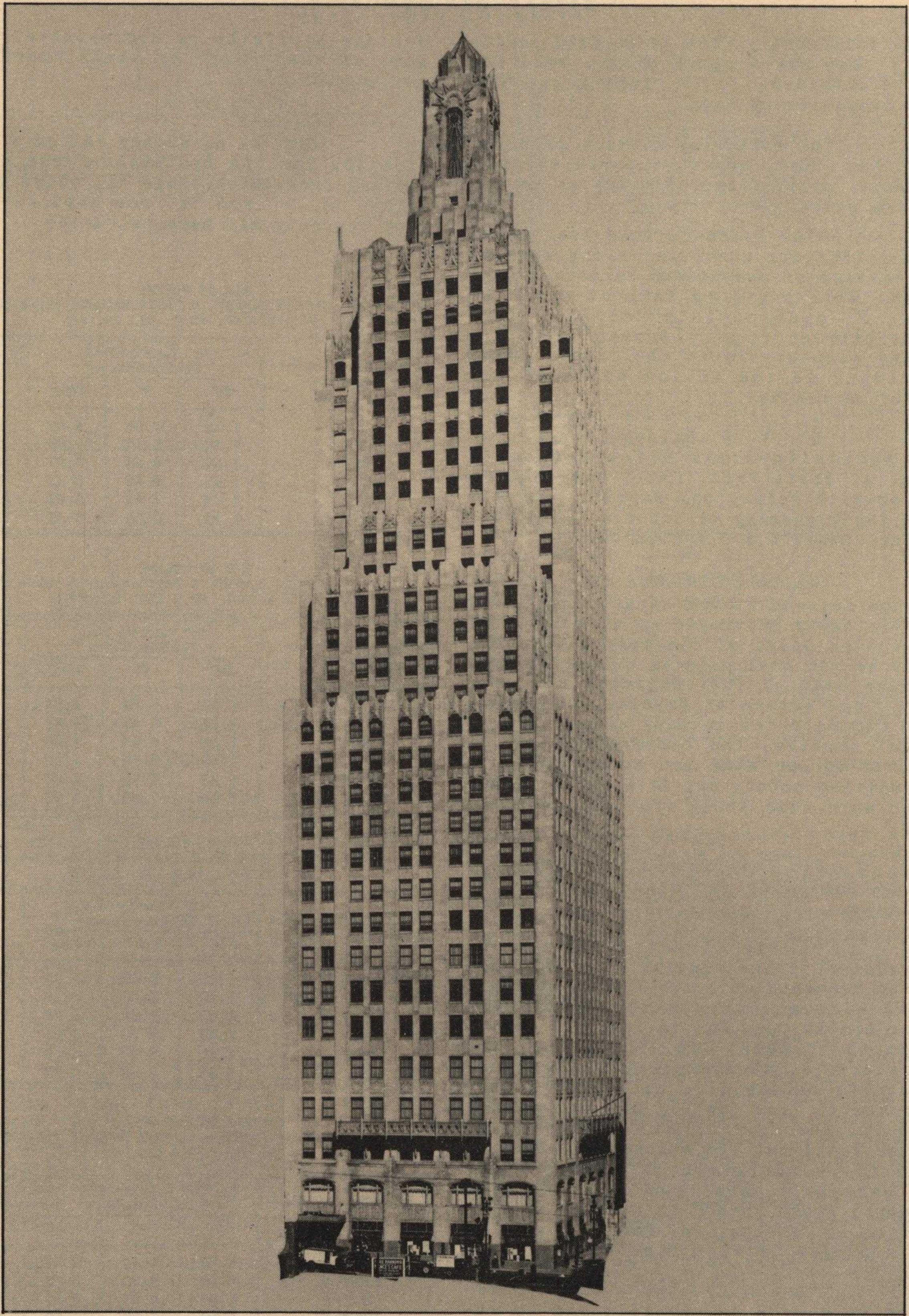
MIX BY VOLUME
1 PART LUMNITE CEMENT, 6 PARTS HAYDITE "BX-4.00"
UNIT WEIGHT, 79.0 LBS. CU. FT.

Maintained Inside Temperature	"r" Value for Wall Thickness Shown			Factor "K"
	4½"	9"	13½"	
75° F.	1.78	3.56	5.34	2.52
400° F.	1.70	3.40	5.10	2.62
800° F.	1.63	3.26	4.89	2.75
1200° F.	1.55	3.10	4.65	2.87
1600° F.	1.50	3.00	4.50	3.00
2000° F.	1.44	2.88	4.32	3.12

MIX BY VOLUME
1 PART LUMNITE CEMENT, 8 PARTS HAYDITE "BX-4.00"
UNIT WEIGHT, 74.0 LBS. CU. FT.

Maintained Inside Temperature	"r" Value for Wall Thickness Shown			Factor "K"
	4½"	9"	13½"	
75° F.	2.22	4.45	6.67	2.27
400° F.	2.12	4.25	6.37	2.36
800° F.	2.02	4.05	6.07	2.47
1200° F.	1.92	3.85	5.77	2.57
1600° F.	1.85	3.70	5.55	2.68
2000° F.	1.77	3.54	5.31	2.79

Table VI



Kansas City Power & Light Bldg., Kansas City, Mo.
Haydite Concrete Superstructure and Floor System with
Haydite Pre-cast Floor Tile Fillers

Professional Bldg., Kansas City, Mo.

Haydite Concrete Superstructure and Floor System

MASONRY UNITS

The American Aggregate Company, the Haydite Manufacturers Association, and the various Haydite manufacturers individually, have sponsored, contributed to, or furnished the material for, numerous tests which have been published as Transactions or Proceedings of various societies, Reports of departmental agencies, Bulletins from various universities and as papers read before meetings of groups interested in masonry units.

While the bulletins, journals, etc., in which this material has been publicized are rightfully the property of the publisher the information obtained on the tests and published thru these mediums is the property of the contributing agent. Under the following headings extraction of the tests pertaining to the material Haydite only is used. No attempt is made to show a comparison between results obtained from Haydite units and results obtained from other units. By adopting this procedure it is believed that no unethical practice is established.

An attempt is made to show, in all cases, the physical properties of the units, method of manufacture, aggregate grading, cement content, etc., and their behavior under the various tests. This information should aid materially, not only in the design of units for various uses but also in the design of structures where units play an important part.

WISCONSIN TESTS

A series of tests was conducted at the University of Wisconsin under the sponsorship of the National Concrete Masonry Association with the Besser Mfg. Co. and Stearns Mfg. Co. as the representatives of machine manufacturers and with the American Aggregate Company, the Celotex Corp., the Waylite Company, the Superock Co. and the National Cinder Conc. Prod. Assn. as the aggregate producers contributing, to determine:

1. Effect of temping or vibration molding for each aggregate

   a. On compressive strength
   b. On density
   c. On absorption
   d. On durability
   e. On yield
   f. On volume change

2. Effect of yield in terms of block per sack for each aggregate

   a. On compressive strength
   b. On weight of units
   c. On absorption
   d. On durability
   e. On volume change

The results were presented in the paper "Tests on Concrete Masonry Units Using Tamping and Vibration Molding Methods" by Kurt F. Wendt and Paul M. Woodworth, published in the A.C.I. Journal, Nov. 1939 and read at the N.C.M.A. convention in Washington, D. C. Feb. 1940 and at the A.C.I. convention in Chicago, Mar. 1940. The author's synopsis follows:

"This paper presents results of a comprehensive, correlated series of tests on concrete masonry units made with seven different aggregates, cinders, Haydite, limestone, Pottsco, sand and gravel, Superock and Waylite. Comparative data show the effect of two different types of molding, vibration and tamping, on compressive strength, absorption, capillarity, specific weight, durability, volume change and thermal expansion coefficient for each aggregate. Similar comparative data are presented for variations in cement content for each aggregate."

The tests were under the direct supervision of Mr. Paul Woodworth, engineer, Cement Products Bureau, P.C.A. representing the National Concrete Masonry Association, who personally supervised the design and manufacture of the various aggregate series. Professor Kurt F. Wendt of the University of Wisconsin conducted the tests. Units were constructed using Haydite, Cinders, Pottsco, Superock and Waylite as the lightweight aggregates with batches designed to produce 45, 3 core units, (1-1/4" face shell, 45% core area) with design mixes to yield three series: 17 blocks per sack of cement, 25 blocks per sack of cement and 33 blocks per sack of cement for each aggregate. Identical amounts of cement were used with all aggregates, being:

252 pounds of cement for mixes V_1 and T_1
169 pounds of cement for mixes V_2 and T_2
128 pounds of cement for mixes V_3 and T_3 per series batch, varying the aggregate to produce the required number (45) of units.

MASONRY UNITS

The vibrated units were produced at the plant of the Midwest Concrete Pipe Company, Franklin Park, Illinois, on a Stearn' Joltcrete machine equipped to produce two 8x8x16", 3 oval core units, and two, 8x8x8" halves of three oval core units in a cycle.

The tamped units were produced at the Best Block Company, Milwaukee, Wisconsin whose equipment consisted of two Besser heavy-duty power strippers, one equipped to make one 8x8x16" three rectangular core units and the other to produce two one-half units.

The regular plant crews at each plant operated the machines under the direction of a representative of the manufacturer of the equipment and in both cases representatives of the aggregate producers were present. In general, about 30 one-half units and 30 full units were made for each batch.

The units were cured for the first 24 hours by placing them in the regular moist curing room in use at each plant where a temperature of between 90° and 110° and a saturated atmosphere, produced by steam jets, was maintained. Following this period of curing the units were stock piled in the usual manner until shipped to the laboratories for testing. Units for compression tests at 7-days, volume change, and temperature coefficient determination were shipped to the laboratory of the Portland Cement Association four days after manufacture. Units for compression tests at 28-days and at 6-months and for absorption, capillarity, and durability tests were shipped to the Materials Testing laboratory of the University of Wisconsin eighteen days after manufacture.

The principal data on aggregate and unit properties; mix, strength, absorption, etc. are presented in Tables VIII to XII which are copies of the data submitted the contributor by the University of Wisconsin.

PHYSICAL DATA ON AGGREGATE

Grading	Weight, Lb. per cu. ft.		Moisture Content as Sampled	Sieve Analysis % Coarser Than							Fineness Modulus
	Damp Loose	Dry Rodded		3/8	4	8	16	30	50	100	
Fine	51.9	62.2	6			13	43	61	69	78	2.64
Coarse	45.7	46.0	6	5	70	96	97	97	97	98	5.60
Combined Fine 45% Coarse 55%		58.5		2	29	40	66	76	81	87	3.81

Table VIII

MIX DATA AND PHYSICAL DATA ON UNITS

Mix No.	Batch Details: Proportions per Sack				Mixing Water Gal/Sack	Water-Cement Ratio, by Wt.	Yield, Units per Sack	Physical Measurement of Units: Wt. of Units			Results at 28 Days*			
		Cement	Fine	Coarse				As Made	7 Day	28 Day	Voids, per cent	Wt. of Concrete, lb/ft.^{3}	Comp. Strength, lb/in.^{2}	Absorption lb/ft.^{3}
V1	Wt. Vol.	94 1	172 2.55	157 3.25	6.2	0.55	16.8	28.2	27.3	26.7	46.7	83.3	1810	7.9
V2	Wt. Vol.	94 1	255 3.80	232 4.80	7.8	0.69	25.8	25.7	25.3	24.3	49.4	78.1	1280	13.1
V3	Wt. Vol.	94 1	339 5.00	308 6.35	11.0	0.98	32.8	26.2	25.3	24.6	48.1	75.8	1150	13.7
T1	Wt. Vol.	94 1	172 2.55	157 3.25	6.3	0.56	16.4	28.6	27.8	27.3	47.6	83.9	1450	12.1
T2	Wt. Vol.	94 1	255 3.80	232 4.80	8.9	0.79	24.4	27.1	26.3	25.3	48.4	79.8	1170	13.6
T3	Wt. Vol.	94 1	339 5.00	308 6.35	11.0	0.98	31.8	26.2	25.5	23.7	48.2	76.8	970	14.2

*As required by Federal Specification SS-C-621, and A.S.T.M.Specification C140-38T.

Table IX

ABSORPTION AND CAPILLARITY DATA

Mix No.	24 Hr. Absorption, Age 28 Days		Rate of Absorption, Ratio $\frac{\frac{1}{2}\text{ Hour Absorption}}{24\text{ Hour Absorption}}$			Suction Rate, lb/block ($\frac{1}{4}$" Immersion in Water)				Height of Water in Block, in 24" Hours
	Per Cent	lb/ft.^{3}	lb/block	Per Cent	lb/ft.^{3}	$\frac{1}{2}$ hr.	1 hr.	5 hr.	24 hr.	
V1	9.5	7.9	0.59	0.59	0.59	0.20	0.25	0.35	0.45	1¼
V2	16.8	13.1	0.86	0.86	0.87	0.50	0.50	0.70	0.80	2
V3	18.1	13.7	0.84	0.84	0.84	0.45	0.55	0.65	0.80	2
T1	14.5	12.1	0.65	0.64	0.64	0.40	0.40	0.45	0.55	1½
T2	17.1	13.6	0.72	0.72	0.72	0.50	0.60	0.65	0.80	2
T3	18.5	14.2	0.76	0.76	0.76	0.50	0.60	0.70	0.95	3

Table X

STRENGTH DATA

Mix No.	Compressive Strength, lb. per sq. in.					Ratio, $\frac{\text{Strength After 100 Cycles}}{\text{Strength at Various Ages}}$			
	7 day	28 day	Controls, air cured 170 day	Controls Adjusted to Log of Age	After 100 Cycles of F. & T.	7 day	28 day	Controls 170 day	Adjusted to Log of Age
V1	1640	1810	2085	2035	2095	1.28	1.16	1.00	1.03
V2	1190	1280	1520	1395	1480	1.24	1.16	0.97	1.03
V3	1000	1150	1410	1345	1250	1.25	1.09	0.89	0.93
T1	1250	1450	1535	1700	1980	1.58	1.36	1.29	1.16
T2	950	1170	1090	1460	1355	1.42	1.16	1.24	0.93
T3	690	970	1005	1340	1345	1.95	1.39	1.34	1.00

Table XI

STRENGTH RATIOS

Mix No.	Ratio of Strengths, Tamped to Vibrated				
	7 day	28 day	Controls, 170 day	Adjusted to Log of Age	F. & T. Specimens
1	0.76	0.80	0.74	0.84	0.95
2	0.80	0.91	0.72	1.05	0.91
3	0.69	0.84	0.71	1.00	1.08

Table XII

In the tabular data the letter V refers to vibrated units and the letter T to the tamped method of production. Numerals designate mixes designed to yield each 17, 25 and 33 units per sack of cement, respectively, thus, V-3 would designate vibrated units with a design mix of 33 units per sack.

The average thermal coefficient of expansion per degree Fahrenheit for the vibrated units was .0000039 and for the tamped units .0000034.

Using the data submitted by the University of Wisconsin, Figure 24 was developed to show more definitely a conversion factor in the aggregate proportions and to reflect graphically the compressive strength and absorption properties in terms of blocks per sack of cement. Figure 25 shows the pounds of cement per block for both vibrated and tamped units in terms of strength and Figure 26 the pounds of water per pound of cement for both types of production in like terms.

The durability data pertaining to Haydite units are shown in Table XIII. Messrs. Wendt and Woodworth explain the durability determination as:

"Durability ratings were arbitrarily based on 3 factors: weight loss and the ratios of strength after 100 cycles of freezing and thawing to the strengths determined at 28 and 170 days. To merit a rating of 'excellent', no loss of weight was permitted and units were required to show a minimum strength

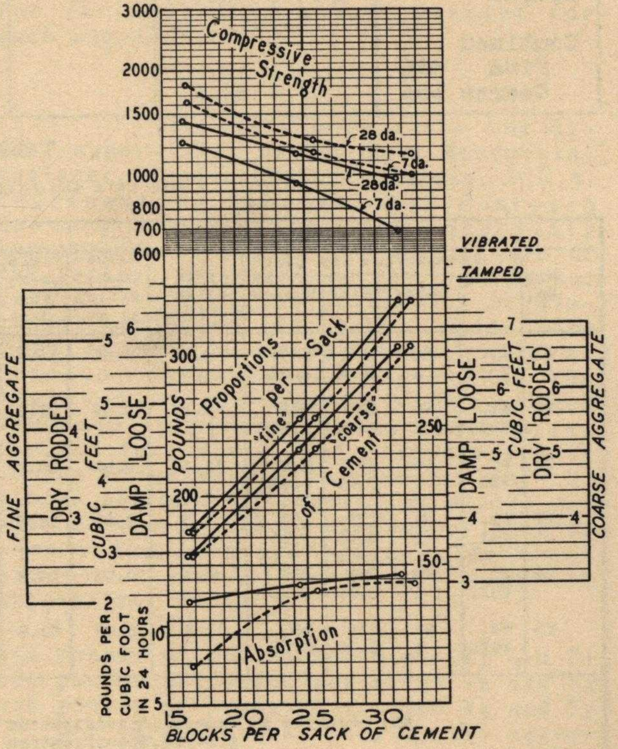


Fig. 24

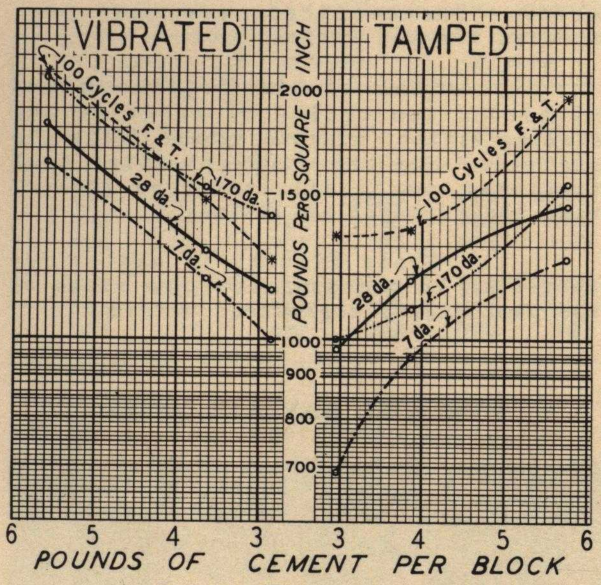


Fig. 25

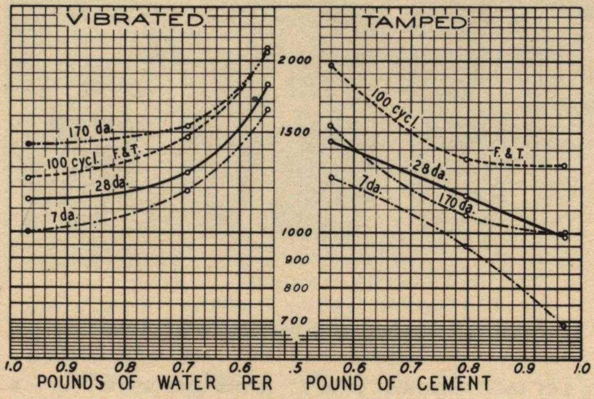


Fig. 26

ratio of either 0.95 at 28 days or 0.90 at 170 days. A rating of 'good' was used when the weight loss did not exceed 2 per cent and strength ratios were over 0.90 or 0.85, respectively. In several instances a rating of 'fair' was used where disintegration was confined to a single specimen, the average weight loss was less than 15 per cent, and strength ratios were within the limits prescribed for a 'good' rating."

DURABILITY DATA

Mix No.	Percentage Change in Weight At		Summary of Observations on Freezing and Thawing Specimens					
	50 Cycles	100 Cycles	15 Cycles	30 Cycles	50 Cycles	65 Cycles	80 Cycles	100 Cycles
V1	+ 1.09	+ 1.00				x	x	x
V2	+ 1.81	+ 2.09		x	xx	xx	xx	xx
V3	+ 2.17	+ 1.14			x	xx	xx	xx
T1	+ 1.70	+ 1.62			x	x	xx	xx
T2	+ 1.32	+ 1.23		x	xx	xx	xxx	xxx
T3	+ 2.20	+ 1.93	x	xx	xxx	xxx	xxx	xxx

All specimens Rated "EXCELLENT"

x Very light spalling
xx Light spalling
xxx Light to medium spalling
* Medium spalling
** Heavy spalling
*** Disintegration

Table XIII

To obtain a numerical value for the "x's", shown in the Wendt and Woodworth Table (XIII), that would reflect a comparative value of durability between the units produced from Haydite aggregate and the units produced from the other light weight aggregates, a percentage demerit system for each of the reported conditions of specimens at the 6 points of observation was assigned, namely, at 15, 30, 50, 65, 80 and 100 cycles of freezing and thawing, by assessing a value of demerits on a geometrically ascending scale for each point, of 2% for "Very light spalling" (x), 4% for "Light spalling" (xx), 8% for "Light to medium spalling" (xxx), 16% for "Medium spalling" (*), 32% for "Heavy spalling" (**), and 64% for "Disintegration" (***), respectively. Additional percentage deductions of 5% for "Good" ratings, 10% for "Fair" ratings, and 20% for "Failure" ratings, with no deductions for "Excellent" ratings were given. Comparative results by this method of evaluation are shown in Table XIV, referring to the other light weight aggregates by arbitrarily assigning a 'letter'.

Mix No. (Units per sack of cement)	Method of Manufacturing	Haydite	Agg. "A"	Agg. "B"	Agg. "C"	Agg. "E"	Average (All)
		% Rating	% Rating	% Rating	% Rating	% Rating	
V1 17	Vibrated	99.0 Ex.	92.7 Gd.	99.3 Ex.	98.7 Ex.	89.3 Gd.	95.8
V2 25	Vibrated	97.0 Ex.	21.0 F.	42.3 F.	47.7 F.	48.8 F.	51.4
V3 33	Vibrated	97.6 Ex.	12.5 F.	13.3 F.*	17.0 F.*	15.2 F.*	30.6
T1 17	Tamped	98.0 Ex.	94.4 Ex.	97.7 Ex.	97.6 Ex.	97.7 Ex.	97.1
T2 25	Tamped	95.6 Ex.	40.0 F.	61.7 Fr.	95.0 Ex.	80.7 Ex.	74.5
T3 33	Tamped	93.6 Ex.	16.5 F.	16.0 F.*	69.7 Fr.	87.3 Ex.	56.6

(Explanation: * 50 cycles only. Ex.: Excellent. Gd.: Good. Fr.: Fair. F.: Failure.)

Table XIV

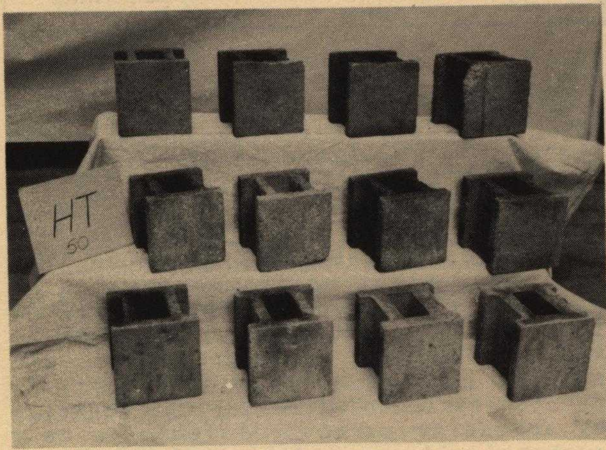
Pertinent comment by the authors, on the Haydite units, follows:

"The Haydite units were all well above the minimum requirements of Federal and A.S.T.M. Specifications for Load Bearing Masonry Units, the lowest 28-day compressive strength being 970 p.s.i. for mix T3. The curves of Fig. 9 show that vibrated units are somewhat lighter than tamped units but are considerably stronger and absorb less water. These effects are most pronounced for the richest mix.

"All of the Haydite mixes withstood 100 cycles of freezing and thawing without visible damage (Figs. 10 and 11); and the strength after such treatment was in all instances greater than the strength at 28-days."

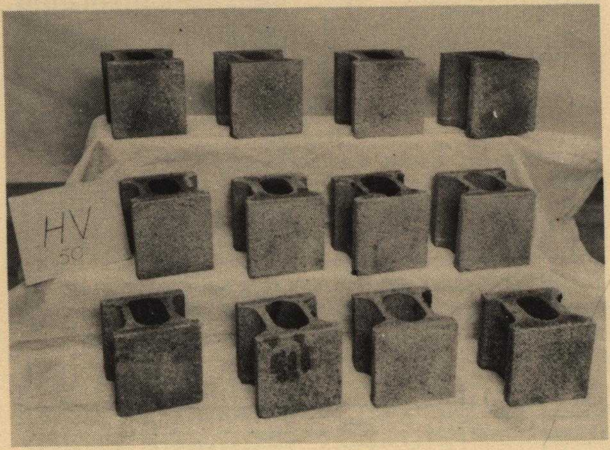
Their Figures 10 and 11 referred to in the quotation are shown by the photographs reproduced herein.

TAMPED HAYDITE UNITS



After 50 Cycles of Freezing and Thawing

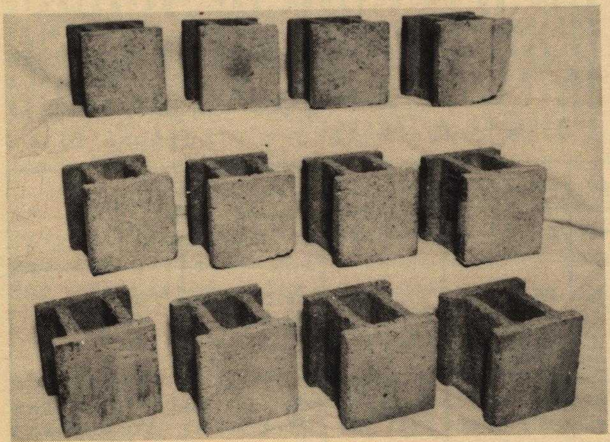
VIBRATED HAYDITE UNITS



After 50 Cycles of Freezing and Thawing

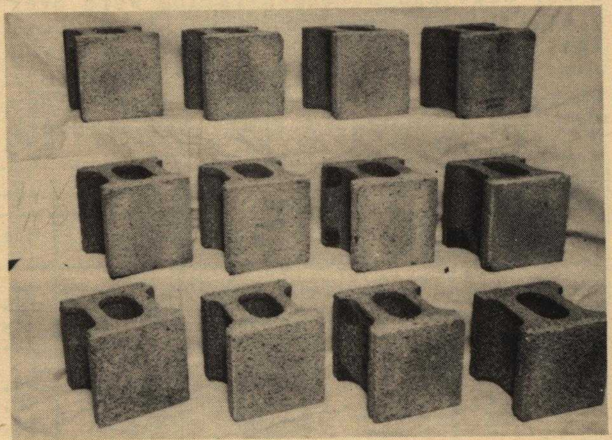
Top row 33 units per sack—Middle row 25 units per sack—Lower row 17 units per sack

TAMPED HAYDITE UNITS



After 100 Cycles of Freezing and Thawing

VIBRATED HAYDITE UNITS



After 100 Cycles of Freezing and Thawing

Top row 33 units per sack—Middle row 25 units per sack —Lower row 17 units per sack

MASONRY UNITS

COMPRESSIVE STRENGTH OF UNITS IN P.S.I. AT:

7 DAYS		28 DAYS		28 DAYS		28 DAYS		28 DAYS		28 DAYS	
HAYDITE		AGG. "A"		AGG. "B"		AGG. "C"		AGG. "E"		AVERAGE A-B-C-E	
V17	1640	V17	1680	V17	1210	V17	1220	V17	1180	V17	1322
V25	1190	V25	1040	V25	940	V25	740	V25	780	V25	875
V33	1000	V33	730	V33	600	V33	660	V33	580	V33	643
T17	1250	T17	1610	T17	1210	T17	1200	T17	1220	T17	1060
T25	950	T25	970	T25	890	T25	930	T25	990	T25	945
T33	690	T33	700	T33	660	T33	740	T33	920	T33	755

Table XV

The compressive strengths of Haydite units at 7-days and the other light weight units at 28-days are shown in Table XV in which an arbitrary letter has been substituted for the name of the aggregate.

The author's conclusions, which are believed to present essential design data, are given as follows:

"8. On the basis of these tests good or excellent resistance to 100 cycles of freezing and thawing is assured if the units show no weight loss at the end of 50 cycles.

"9. Present specifications of 700 p.s.i. compressive strength at 28 days and a maximum absorption of 15 or 16 lb. per cu. ft. of concrete are inadequate to insure masonry units which will be sound and durable under severe exposure conditions.

"10. There is no apparent correlation between absorption per se and durability. Rate of absorption, however, expressed as the ratio of absorption after 1/2 hour immersion to absorption after 24 hours immersion in water, shows promise as a criterion for durability rating.

"11. A satisfactory specification based on these tests which insures excellent resistance to freezing and thawing for light weight aggregates is a compressive strength at 28 days of 900 p.s.i. based on gross area and a rate of absorption not in excess of 0.87. The latter measure, however, requires further confirmation before it can be recommended for use in specifications.

"12. A minimum compressive strength of 1000 p.s.i. of gross area is recommended for load bearing units as the simplest and most equitable specification for insuring reasonably satisfactory behavior under severe exposure conditions.

* * * * * * * * * * * *

"14. Further studies should include the effect of differences in the proportion of aggregate passing the 50 mesh sieve on absorption rate, strength and durability; and possible correlation of various methods of determining absorption rate with strength as a measure of durability."

The tests were followed from their inception and the results reviewed by a representative of each the American Aggregate Company and the Western Brick Company. Upon the publication of the results comparative data of the various units were extracted from the original report and published for private use. This review led to the following general conclusions:

1. Strength: Haydite units in general were stronger at 7-day age than were the units produced from any other light weight at 28-day age. After undergoing 100 cycles of freezing and thawing Haydite units were stronger then than at any earlier age. No other light weight unit had this record.

2. Durability: Haydite units alone passed 100 cycles of freezing and thawing "without visible damage", and with all specimens gaining weight over this period. The durability ratings for all mixes of Haydite, including the leanest, are "Excellent." No other of the lightweight units have this rating for 100% of specimens. Such durability tests are indicative of the ability of the units to withstand years of severe exposure conditions in a wall.

3. Yield: Haydite units averaged better than eight more full-sized units per sack of cement, and from 2 to 13 more units per cu. yd. of aggre-

gate, for different mixes, than competitive light-weight units, of similar strength.

4. Absorption and Capillarity: Haydite units had rates of absorption of water well below every similar mix made with other lightweight aggregates. Its capillarity, in all series, averaged well below others tested. The rate of absorption indicates a fair measure of durability, according to the authors.

5. Unit weight of Concrete: Haydite units, in addition to having highest ratings in strength, durability, yield, etc., were the lightest in weight of all units tested, in all series.

6. Weight Changes During Freezing and Thawing: Haydite units were alone, of all units tested, able to meet the requirements of "no weight loss after 100 cycles of freezing and thawing" with every specimen. The authors state meeting this requirement at 50 cycles to be sufficient for "durable units".

FIRE RESISTANCE

The results of tests reported in the paper "Tests of the Fire Resistance and Stability of Walls of Concrete Masonry Units" by Mr. C. A. Menzel were presented at the 34th Annual Meeting of the American Society for Testing Materials and published in the 1931 Proceedings of the Society. The purpose of the tests and paper is more properly described by the following synopsis:

"This paper presents the principal results thus far obtained in a comprehensive and systematic investigation of the fire resistant and load-carrying properties of approximately 100 walls of concrete masonry units when subjected to standard fire endurance and load tests. The tests covered studies of the relative influence of such factors as type and grading of aggregate, cement content, design of unit, type of mortar, workmanship, and application of plaster.

"With the exception of size of wall, the tests were conducted strictly in accordance with Standard Specifications for Fire Tests of Building Construction and Materials. Both because of limitations in the space available for the test equipment and the excessive cost in a series of tests of this magnitude, walls about 5-1/2 ft. wide and 6 ft. high with a total area of about 33 sq. ft. were employed instead of walls 9 ft. in height and 100 sq. ft. in area required by these specifications. To compensate for the reduction in size of the test walls as well as to improve the precision with which such tests are usually conducted, a particularly rigid test technique was adopted. It is believed that the technique followed gives a reliable basis for comparison of the relative fire-resistant properties of the walls and of the relative influence of the various factors studied.

"Information is presented on the load-carrying ability of the walls before and after severe fire exposure for a wide range in composition and design of the units and of the type of mortar and workmanship employed in the construction of the walls."

The manufacture and curing of the units is explained by the authors as:

"To control and facilitate the making of the units and the construction of the wall specimens in a regular and routine manner, a block machine and a mixer of standard make were installed. The block machine was provided with 6 sets of mold boxes and tampers with which the typical designs of units illustrated in Figs. 8 and 9 were made.

[Figures 8 and 9 referred to in the author's description are shown in Figure 27.]

"Each set of units was molded from a carefully proportioned weight mixture of aggregate, cement, and water. The portland cement was a mixture of four brands purchased in Chicago. The correct quantities of aggregate and cement were first mixed dry for 1 minute. As much water as possible was then added to the dry mixture but not so great an amount as would appreciably impair the handling properties of the units during and after molding. The consistency was therefore, as wet as practicable for units made by the 'tamped' process. The molds were filled in 2 layers, the amount of tamping of each layer being maintained constant for each design of unit.

"Immediately after molding, the units were removed to a room where they were 'moist cured' for 5 days at a temperature of 70° F. and in a saturate foggy atmosphere obtained by atomizing nozzles. During the 5-day period a slight increase in weight due to the absorption of moisture was recorded. Upon removal from the moist room, the blocks were stored 9 days in ordinary air of the laboratory during which time

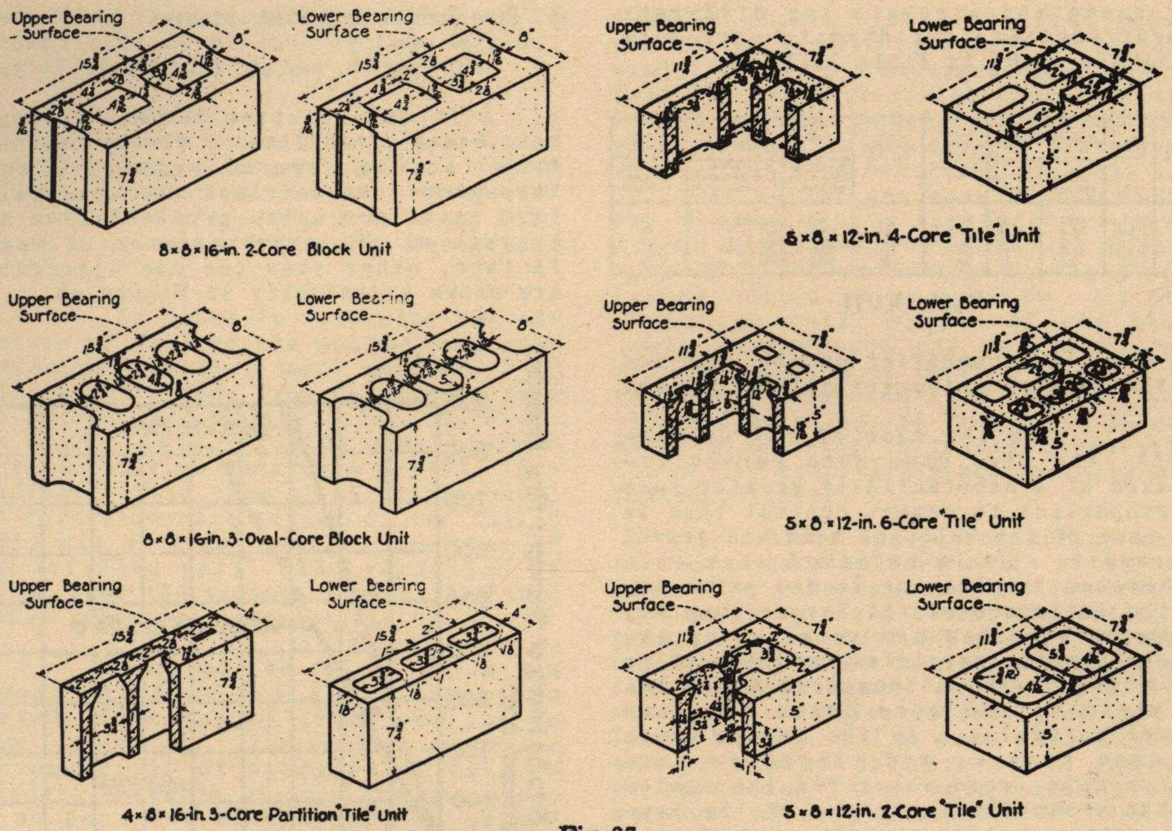


Fig. 27

they lost weight rapidly. They were laid up into test walls at age of 2 weeks."

The basis for evaluating performance of walls was compared principally on two criteria: Fire Endurance Period and Stability or Load-carrying Ability after fire exposure.

By fire endurance period is meant the period during which the test walls sustained a working load of 80 lb. per sq. in. of gross sectional area under standard fire exposure, without transmission of flame, hot gases, and high temperatures to the unexposed side as defined by the standard fire test specifications. As only one of the walls failed under load, and none by the transmission of flame and gases hot enough to ignite ordinary combustible materials, their fire endurance periods were determined by the temperature rise on the unexposed face. The requirements of the standard are that the average temperature rise (above initial temperature of wall) of the unexposed face shall not exceed 250° F. and that the maximum rise at any point where temperature measurements are taken, shall not exceed 325° F.

While the Standard Specifications do not require that bearing walls subjected to fire endurance tests carry excess loads after fire exposure, ability to carry such loads, as determined from ultimate strength tests, is a very desirable property and provides direct evidence regarding the extent of the fire damage to wall assemblies. Information on the relative stability of the various walls was therefore obtained by comparing their ultimate strengths after fire exposure and by comparing the ratios of ultimate wall strength after fire exposure to the original strength of the individual units. The latter method was of particular value and was used in most of the tests as it was believed to compensate for variations in the original strength of the units.

The fire endurance period for different grading of Haydite aggregate in addition to the physical properties of the Haydite units subjected to such test is shown in Table XVI and the fire

Fineness Modulus	Mix by Volume	Cement Content		Average Weight of Air-Dry Block, lb.	Fire Endurance Period, Minutes	Ultimate Strength, lb. per sq. in., Gross Area		Ratio of Wall Strength to Original Strength of Unit, per cent
		Blocks per Sack	Lb. per Block			Block Before Fire Exposure	Wall After Fire Exposure Indicated	
4.75	1:7.0	21.4	4.39	23.8	146	480	145 (3½ hr.)	30
4.25	1:7.0	21.1	4.45	25.6	159	680	273 (")	40
3.75	1:7.0	21.3	4.41	27.2	162	890	324 (")	36
3.00	1:7.0	21.2	4.43	28.2	175	930	333 (")	36
2.07	1:7.3	21.0	4.47	28.5	180	840	273 (")	32

Table XVI

endurance and strength for different cement contents for Haydite aggregate units are shown in Table XVII.

Fineness Modulus	Mix by Volume	Cement Content		Average Weight of Air-Dry Block, lb.	Fire Endurance Period, minutes	Ultimate Strength, lb. per sq. in., Gross Area		Ratio of Wall Strength to Original Strength of Unit, per cent
		Blocks per Sack	lb. per Block			Block Before Fire Exposure	Wall After Fire Exposure Indicated	
3.25	1:10.0	29.1	3.23	26.8	160	750	256 (3½ hr.)	34
3.25	1:8.0	23.6	3.98	27.8	174	1000	445 (")	44
3.25	1:7.0	21.1	4.45	28.2	178	1120	358 (")	32
3.25	1:5.0	15.3	6.15	30.0	194	1575	580 (")	37
3.25	1:3.0	9.8	9.60	32.8	221	2100	770 (4 hr.)	37

Table XVII

In commenting on the behavior of the Haydite units the author states:

"In the case of the Haydite walls, the fire endurance period increased at a substantially greater rate in proportion to cement content than in the case of the walls of sand and gravel aggregate. It is believed that this difference in behavior is due primarily to the influence of the larger quantity of water absorbed and retained by the porous Haydite particles during molding and moist curing as compared with that retained by the more dense sand and gravel particles. As the cement paste becomes richer, and therefore more impermeable, more water remains sealed in the vesicular structure of the Haydite concrete. The vaporization of this water absorbs heat and therefore prolongs the fire endurance period beyond the time that would logically result from the dehydration of the cement alone.

"The fact that the fire endurance period remained proportional to the cement content, in spite of the accompanying variations in the structural characteristics of the blocks is of interest in showing the greater influence of the chemically active ingredient as compared to variations in physical structure."

In the results shown under the author's subheading "Fire Endurance as Effected by Character of Aggregates", Haydite from one source only was investigated. The features of this particular aggregate and the properties of the units produced from it are:

1. Fineness Modulus 3.50
2. Unit Weight based on dry rodded, 0 to 3/8", aggregate graded to Fineness Modulus pounds per cubic foot 67
3. Mix by volume 1:7.0
4. Cement Content
   (a) blocks per sack 21.2
   (b) pounds per block 4.43
5. Average Air Dried, weight
   (a) per block 27.6
   (b) per sq. ft. of wall 33.5
6. Fire Endurance Period, minutes
   (a) wall 168
   (b) per lb. per sq. ft. of wall 5.01

The relation between strength before and after fire of blocks produced from the one type of aggregate used throughout the test and the same relative ratio for units produced from aggregate of six other sources of manufacture, other than the one aggregate, are shown graphically in Figure 28.

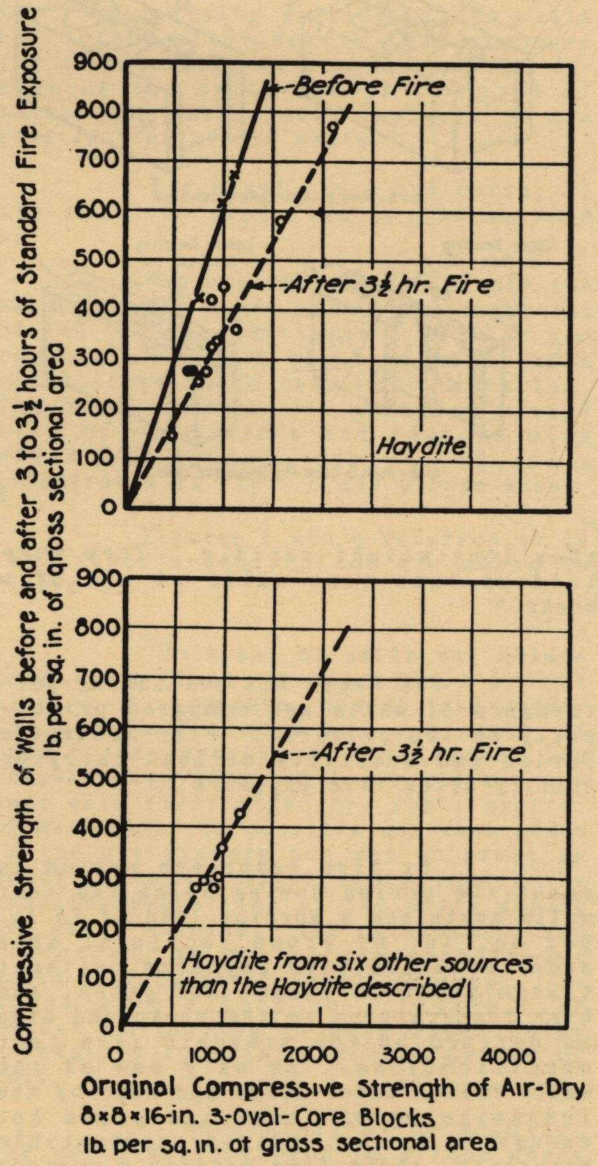


Fig. 28

The data presented in Figure 28 can be utilized to select the strength of unit necessary to produce any given wall strength after fire exposure. For example, with a wall of Haydite units, to have a strength of 700 lb. per sq. in. after exposure, the dia-

grams show that it will be necessary to use units of about 1200 lb. per sq. in. initial strength.

Walls were laid up with 1:3 portland cement mortar plus 15% hydrated lime by volume of cement, being 1 volume of cementitious material to 3 volumes of dry rodded Elgin sand, 0 to #14, F.M. 1.9 to 2.0, with workmanship designated "Good".

In tests to determine the advantage of filling the hollow core area spaces experiments were conducted by filling units made from calcareous sand and gravel with Celite, slag, Haydite, and sand. This revealed a very great increase in fire endurance period. Regardless of the type of materials used, the fire endurance period of the filled walls was at least 2-1/2 times that of the unfilled wall. The variation in effect from the various type of fillings seemed relatively immaterial.

Each of the filled walls was exposed to fire for 6-1/2 hours and tested for strength after cooling to room temperature. The results showed an average ratio of strength of wall to original strength of unit for the group of 20 per cent as compared to 28 per cent for the unfilled wall after 3 hours of fire exposure. This indicates that filled walls made of units having a strength of 700 lb. per sq. in. would be able to carry the normal working load of 80 lb. per sq. in. of gross sectional wall area during and after 6-1/2 hours of severe fire exposure with a margin of safety of at least 50 per cent.

Table XVIII shows the effect of plaster on fire endurance and strength of 8" walls made with 3 oval core Haydite blocks.

Plastered Face	Fire Endurance Period of Wall, Minutes	Percentage Increase on Unplastered Wall	Ratio of Wall Strength, After Fire Exposure Indicated, to Original Strength of Unit, Per Cent
None............	160	..	36 (3½ hr.)
Fire Face........	197	23	43 (3½ hr.)
Unexposed Face...	212	32	43 (3½ hr.)
Both Faces.......	267	67	43 (4½ hr.)

Table XVIII

Gypsum plaster was used, applied in three coats with a combined thickness of not less than 3/8 in. nor more than 1/2 in. The first or scratch coat consisted of "bondcrete", a wood pulp gypsum plaster applied without sand to a thickness of about 1/16 in. The second or brown coat consisted of a mixture of 1 part of hair-fibered gypsum plaster to 4 parts by weight of dry lake sand applied to a thickness of about 3/8 in. The third or finish coat consisted largely of lime putty with the addition of gypsum gaging and fibered plaster and was applied to a thickness of about 1/16 in. The weight per square foot of the dry set materials in the three coats ranged as follows: scratch coat 0.50 to 0.55 lb.; brown coat 3.4 to 3.5 lb.; finish coat 0.50 to 0.55 lb. On this basis the total weight of the three coats ranged from 4.4 to 4.6 lb. and averaged about 4.50 lb. per sq. ft. The walls were seasoned from 45 to 60 days before plastering and from 70 to 85 days after plastering in freely circulating air at the temperature and humidity of a heated building.

Since the period during which the bare and plastered walls of Haydite aggregate were exposed to fire varied from 3-1/2 to 4-1/2 hours, the effect of plaster on strength after fire exposure can be determined only in a general way from a comparison of the ratios of wall strength to original strength of unit in Table XVIII. Walls made with Haydite and plastered on either the exposed or unexposed faces were considerably stronger after 3-1/2 hours of fire exposure than the bare wall exposed for the same period. It appears, therefore, that the application of plaster to one or both faces of the wall resulted in an appreciable improvement in strength after the same or somewhat longer periods of fire exposure. The use of Haydite plaster would have shown an additional improvement.

The results of a test using a "mixture of two widely different aggregates" are shown in Table XIX. One wall consisted of units made entirely from sand and gravel graded to a Fineness Modulus of 4.50, another from fine and coarse Haydite graded to a Fineness Modulus of 4.00 and a third from a mixture of equal volumes of these two aggregates (Fineness Modulus 4.25). While the mix for the different aggregates varied from approximately 1 to 7 to 1 to 8 the cement content was practically constant throughout and averaged 4.50 pounds per unit.

Aggregate	Fire Endurance Period, Minutes	Original Strength of Units, Lb. per Sq. In. Gross Area	Strength of Wall After 3-Hour Fire Exposure, Lb. per Sq. In. Gross Area	Ratio of Wall Strength to Original Strength of Units, Per Cent	Total Expansion of Walls (6 Ft. High) During Fire Exposure, In.
All gravel.....	141	1860	460	24	0.38
Mixture........	157	1390	495	36	0.24
All Haydite....	177	975	420	48	0.11

Table XIX

One of the most useful and important developments of the strength tests was establishment of a straight-line relationship between the original compressive strength of the units and the compressive strength of the walls before and after exposure to fire. This relationship shows that the strength of the wall is approximately proportional to the strength of the units over a wide range in strength of unit, type and grading of aggregate, design of unit and cement content.

STABILITY

The results of a test carried on at the Materials Testing Laboratory, University of Illinois, in cooperation with the Portland Cement Association and the Concrete Masonry Association were presented as a paper "Tests of the Stability of Concrete Masonry Walls" by F. E. Richart, P.M. Woodworth and R. B. B. Moorman at the 24th Annual Meeting of the A.S.T.M. June 1931, and published in the Proceedings of that Society.

The tests were planned primarily to furnish information on the behavior, under load, of wall panels of sufficient size to represent building conditions and also to determine a correction factor to be used for wallette (32" long and 48" high) strengths to make them directly comparable with the various large panels.

The walls were tested in Compression, axial and eccentric, and in Flexure. Justification of wallette sections and a summary of the results is given in the following extraction of the author's synopsis:

"From the results of the tests several fairly definite relations were established. The compressive strength of large walls was shown to be quite closely dependent upon the compressive strength of the units used therein, and the average ratio of strength of wall to that of unit was found to be 0.53. The ratio of compressive strengths of large and small walls was found to be fairly constant, with an average value of 0.91. This would seem to establish the propriety of using wallette tests as indicative of the strength of wall construction, using the reduction factor found. Eight-inch walls with face-shell mortar beds were found to have four-fifths of the compressive strength of similar walls with full mortar beds. The effect of other variables included in the investigation, such as type of aggregate, strength of mortar and thickness of walls was found to be less definite. Composite walls of face brick and concrete units showed satisfactory behavior and strength."

The units were manufactured on contract using an Anchor hopper feed, mechanical tamper and stripper machine. The proportions of fine to coarse aggregates, in general, followed the plant practice and were designed to produce units with a fairly rough texture. The units were cured for 48 hours in a steam curing room. The temperature was held at 100° at night and 80° in the day time. Upon removal from the curing room the units were stock piled under cover until 21 days old when they were delivered to the laboratory. The cement content of the different lots was varied with the object of producing units in 2 strength ranges; one just passing specification requirements of 700 p.s.i. at 28 days and the other having a strength of approximately 1100 to 1200 p.s.i.

The retained percentage of the fine and coarse Haydite is shown in Table XX. For comparative values the No. 30 and the No. 50 screen in this table have the same "openings" as the Tyler Standard No. 28 and No. 48, respectively.

PERCENTAGE RETAINED ON SIEVE

AGGREGATE	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	FINENESS MODULUS
Western Haydite, fine.....	0	1	11	43	62	73	80	2.70
Western Haydite, coarse...	6	75	96	97	97	97	97	5.65

Table XX

Haydite aggregates were mixed 2 minutes wet with about 1/2 of the mixing water added and three minutes more after cement and the balance of the water were added. The proper consistency was determined by the plant operator

LOT	TYPE OF AGGREGATE	WEIGHT OF CONCRETE, LB. PER CU. FT.	WEIGHT OF UNIT, LB.	ABSORPTION, LB. PER CU. FT.	MOISTURE IN UNIT, PER CENT		COMPRESSIVE STRENGTH, LB. PER SQ.IN., GROSS AREA		
					28 Days	60 Days	7 Days	28 Days	60 Days
8 by 8 by 16 in. Units; 3 Oval Cores; Core Area 37 per cent									
No. 2	Haydite	75	25.9	14.4	3.9	1.9	490	760	820
No. 6	Haydite	77	27.6	17.8	8.7	4.5	630	950	1280
No. 16	Haydite	74	25.7	15.8	6.1	2.6	640	710	720
No. 18	Haydite	75	26.9	13.3	8.0	3.4	620	740	1040
8 by 12 by 16 in. Units; 3 Oval Cores; Core Area 39 per cent									
No. 15	Haydite	75	36.1	15.6	9.0	3.4	480	670	670

Table XXI

based upon the appearance of the units. Each block was tamped from 10 to 12 times with each of the tamper feet. The details of concrete mixes used in the manufacture of units are shown in Table XXI.

Physical properties of the units are shown in Table XXII. Each value represents tests of 5 units, except the values for unit weight which are based on tests of three units.

LOT	TYPE OF AGGREGATE	MIX BY WEIGHT			WATER ADDED AT MIXER, LB.	MOISTURE IN AGGREGATE, PER CENT		FINENESS MODULUS OF COMBINED AGGREGATE	NUMBER OF UNITS PER SACK OF CEMENT
		CEMENT, LB.	AGGREGATE Fine Damp, lb.	AGGREGATE Coarse Damp, lb.		Fine	Coarse		
No. 6	Haydite	94	185	185	52.0	7	9	4.17	16
No. 15	Haydite	94	250	250	67.0	7	9	4.17	15
No. 16	Haydite	94	250	250	75.0	7	9	4.17	22
No. 18	Haydite	94	195	195	58.0	7	9	4.57	17

Table XXII

The proportions of the two mortar mixes used were based on dry, rodded volume of sand which was graded to pass a No. 16 sieve.

The 1:1:4-1/2 mix of cement, lime and sand per dry volume is not greatly different from the 1:1:6 mix frequently used in construction. The 1:3 cement mortar with 10% of lime by weight of cement is representative of lean mortars and under field conditions of measurement would be denoted as about 1:3-3/4 mix.

The relation between the strength of the wall and the strength of the unit with the two types of mortars and for all types of aggregate has been found to follow the equation: $W = 0.53U$ in which $W =$ compressive strength of large wall and $U =$ compressive strength of unit both in terms of p.s.i.

In commenting upon the effects of mortar bed, the authors state:

"In planning the tests it was decided to lay the units in a full mortar bed, as representative of good supervised construction. At the same time, in recognition of the fact that in some localities it is common to bed only the outer face shells of the units, the walls of lots 1, 2 and 3 were laid up in both ways, thus affording a comparison of results from 9 large walls and 6 wallettes made with each style of mortar bed. The results are quite consistent for the three lots and the two sizes of wall. The ratio of wall strengths with face shell bedding to those with full bedding is as follows: Large walls: lot 1, 0.79; lot 2, 0.81; lot 3, 0.74; wallettes: lot 1, 0.84; lot 2, 0.83; lot 3, 0.76. The average for the six values is 0.80. For the oval-core units to which these data apply, the cores are 4-7/8 in. wide, leaving the face shells with a minimum thickness at the core of 1-1/2 in. Considering that the width of the mortar bed on the face shells might average 2 in., the ratio of the bedded area to the net area of the unit is very nearly 0.8. Hence it may be said that for the 8 by 8 by 16-in. units the ratios of wall strengths are substantially proportional to the bearing areas of the mortar beds, and that this ratio may be taken at about 0.8. It seems reasonable that this factor might be applied to estimate the strength of other walls, such as those of lots 4 to 11, assuming that they were to be laid with face shell bedding."

The walls were built by a union mason and helper, hired by the hour, and followed standard practice, except where different types of mortar and bedding were required by the schedule. Vertical joints were not filled, beyond buttering the edge of the unit as laid and final pointing of joints. In the brick courses of the composite walls, the mortar bed was spread, not furrowed. In the walls, in which backup blocks of Haydite were used, each header brick was placed over a web of the concrete unit.

The authors report the following:

"However, it was found after the walls were tested that through error on the part of the mason only a small percentage of the webs of Haydite units directly above the header courses were effectively bedded, while the webs of cinder units were fully bedded. This unintentional difference in workmanship makes impossible a comparison between the walls of lots 16 and 17, since in lot 16 the units have virtually a face-shell mortar bed, and in lot 17 a full mortar bed was used.

"In general the main group of walls probably represent average building construction in this locality."

The stability features of Haydite unit walls are shown in Table XXIII.

Large Walls - 6 ft. long, 9 ft. 6 in. high, tested in compression and flexure.
Small Walls - 2 ft. 8 in. long, 4 ft. high, tested in compression.
All walls built when units were 28 days old, stored in air of laboratory and tested 32 days later.
Strengths of walls and units are based on gross areas.
Compressive strength of units given are from 60-day tests.
Compressive strength of mortars from 2 by 4 in. cylinders, 32 days old.
All units manufactured in products plants under usual conditions.
Mortar joints, full mortar bed except wall marked 2HS which is bedded on face shells only.
Composite walls, 4-in. face brick, 8-in. concrete back-up unit.
Eccentric loads applied at edge of middle third of wall thickness.
The unit stresses given for eccentrically loaded walls are the average unit stresses.

WALL	TYPE OF UNIT	AGGPEGATE	MORTAR MIX BY VOLUME, DRY RODDED	MAXIMUM LOAD ON WALLS — LARGE, lb.	MAXIMUM LOAD ON WALLS — LARGE, lb. per sq. in.	MAXIMUM LOAD ON WALLS — SMALL, lb.	MAXIMUM LOAD ON WALLS — SMALL, lb. per sq. in.	COMPRESSIVE STRENGTH, lb. per sq. in. — UNITS	COMPRESSIVE STRENGTH — MORTAR, LARGE	COMPRESSIVE STRENGTH — MORTAR, SMALL	MODULUS OF RUPTURE OF LARGE WALL, lb. per sq. in.	RATIO OF STRENGTH OF LARGE WALL TO STRENGTH OF SMALL WALL	RATIO ... OF UNIT
AXIAL LOADING													
2HF 1	8 by 8 by 16 in. 3-oval-core	Haydite	1:1:4½	267 000	465	136 600	540		1230	1230	47		
2				246 000	430	99 400	395		730	730			
3				271 000	470				1130				
			Average	261 300	455	118 000	470	820				0.97	0.56
2 HS 1	8 by 8 by 16 in. 3-oval-core	Haydite	1:1:4½	208 000	360	91 950	365		960	960			
2				218 000	380	103 000	410		780	780	28		
3				217 000	375				1250				
			Average	214 300	370	97 475	390	820				0.95	0.45
6HF 1	8 by 8 by 16 in. 3-oval-core	Haydite	1:1:4½	254 600	445	131 150	520		1380	1670	18		
2				269 400	470	129 850	515		1380	1670			
3				233 700	405				1670				
			Average	252 600	440	130 500	520	1280				0.85	0.34
15HF 1	8 by 12 by 16 in. 3-oval-core	Haydite	1:1:4½	320 000	370	136 000	360		1070	1070	27		
2				308 000	355	140 600	375		840	1070			
			Average	314 000	365	139 300	370	670				0.99	0.54
16HS 1	8 by 8 by 16 in. 3-oval core	Haydite	1:1½:4½	446 000	495	237 000	585		1260	1020			
2		and Brick		532 000	595	279 800	690		1900	1020	38		
			Average	(489 000)[d]	(545)[d]	(258 400)[d]	(640)[d]	(520)[c] 720				0.85	(1.05)[c] (0.76)[d]
ECCENTRIC LOADING													
18HF 1	8 by 8 by 16 in. 3-oval-core	Haydite	1:1:4½	217 000	375	110 600	440		990	990			
2				235 000	410	129 000	510		900	900			
3				235 000	410				960				
			Average	229 000	400	119 800	475	1040				0.84	0.38

c = Strength of offset blocks used in alternate courses of composition walls.

d = These walls laid up, by error, with face shell bedding.

Table XXIII

PILASTERS

One of the series of tests conducted at the Ohio State University, in cooperation with the Common Brick Manufacturers Association, to determine the various properties of brick and masonry units, furnished the material for Engineering Experiment Station, Bulletin 60, "Strength of Concrete Block Pilasters under Varied Eccentric Loading" by J. R. Shank and H. I. Foster. The Hydraulic-Press Brick Company contributed the Haydite units and the service of Mr. McCall and Mr. Earle of the company's engineering staff.

The initial premise for the test is indicated by the following quotation from the Bulletin:

"Concrete blocks are used in building construction for exterior walls that support roof trusses, beams, and floor girders. Service garages, small workshops, factories and storage buildings afford common examples of this construction. The trusses, beams, or girders usually rest on the walls at points between vertical rows or windows. If the spans are long, heavy loads are produced on the walls. To carry these loads the walls are usually strengthened by thickening on the inside, under the beam or truss bearing, to form square internal pilasters. A section of wall between windows, with the pilaster in the middle, makes up a pier. Tests of such piers are reported in this bulletin.

"The usual procedure in erecting buildings of this sort is to build the walls with their pilasters up near to the elevations of the beam or truss supports, then to bed bearing plates

accurately to proper elevation and level, then place the beams. Until a beam deflects under its load it will bear over the entire area of contact with the bearing plate. When deflection occurs the beam will be slightly curved and the bearing ends no longer level. Greater pressures will then occur at the edges of the pilasters, thus producing eccentric loadings. This condition is illustrated by the exaggerated diagrammatic sketch, Fig. 1.

"Deflections in terms of the span of beams in buildings are usually limited to 1 in 360. The deflection limit for a 30-foot span would then be 1 inch. A steel beam with a modulus of elasticity of 29,000,000 pounds per square inch, uniformly loaded on a 30-foot span, would have to be 16.88 inches deep to have a deflection of 1 inch when the maximum fiber stress is 18,000 pounds per square inch. The slope of the elastic line at the reaction point is 0.00889 or 30.5 minutes of arc for a uniformly loaded beam having a deflection of 1 in 360.

"Figure 1 shows only a partial contact between the deflecting beam and the bearing plate for maximum deflection conditions. Whether there is full contact or only partial contact depends upon the flexibility of the pier and the masonry of the pier. Hard non-yielding units of large size laid up in hard mortar would be expected to show less area of contact and consequently greater eccentricity of loading. The modulus of elasticity of the masonry of the pier is the measure of this yielding or non-yielding property. Figure 1 illustrates conditions at working load and at maximum deflection. Loadings less than working loads would produce less deflection, less slope, and less eccentricity."

The Figure 1 referred to in the above quotation is re-drawn as Figure 29.

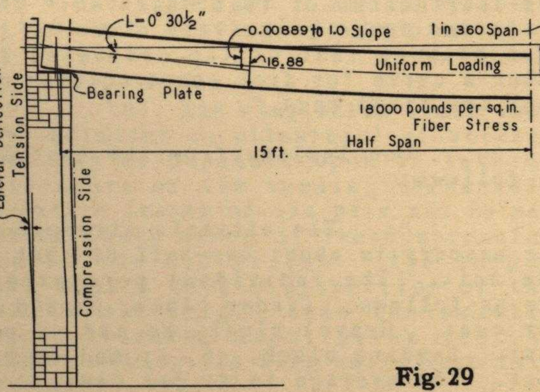


Fig. 29

The Haydite blocks were made at Columbus, Ohio, from Haydite produced by the Hydraulic-Press Brick Company at South Park, Ohio. The mixing was done in a batch mixer which was essentially a stationary horizontal cylinder with the upper part open. The action was produced by twelve blades moving near the inside wall of the cylinder. These were connected radially at six points to a central revolving shaft, two connecting arms opposite to each other at each point. The two blades connected at each point had opposite inclinations to the turning action, one tending to move the material to one end of the cylinder and the other to the other. The shaft speed was 10 r.p.m.

The mixing was performed on 1300 pounds of Haydite and ten gallons of water for two minutes, after which two sacks of cement and ten more gallons of water were added and mixed for not less than 15 minutes more. This batch made 48 or 50 blocks 4x8x16 inches which is somewhat less than one-half cubic yard of concrete. About four to four and one-half bags of cement were therefore used for one cubic yard of solid Haydite concrete.

The blocks were made in an "Anchor" machine. They were transported from the machine to a curing tunnel about 100 feet long and left without further treatment for twenty-four hours, after which they were stored in the yard.

The blocks which were used for these tests were made in the summer time and were about five days old when taken to the laboratory. They were tested about thirty days later.

Three types of building block construction using Haydite blocks were used in the series. They were made into the following pier sizes: For 8" walls; 2 blocks or 32" long with a 4x16" Pilaster projection making a pilaster of 12x16" and for 12" walls; 2 blocks or 32" long with a 4x6" Pilaster projection, making a pilaster of 16". No. 3, the 12x16" pier, was 10 ft. high and No. 6, the 16x16" pier, is 14 ft. high. One other large pier was made using special 12x16" Haydite-units, designated as Pier No. 7. The plates used on the smaller pier were 12x16x1/2" thick and those for the larger pier 16x16x1/2". A diagram of the piers is shown in Figure 30.

PIER NO.	TYPE OF AGGREGATE	SIZE OF UNIT	NO. OF CELLS	WEIGHT	ABSORPTION RANGE	AVERAGE	GROSS AREA UNDER LOAD	COMPRESSIVE STRENGTH AVERAGE TOTAL	AVERAGE UNIT STRENGTH	RANGE OF UNIT STRENGTH	MORTAR COMPRESSIVE STRENGTH AVERAGE	RANGE
				(lbs.)	(lbs./cu.ft.)	(lbs./cu.ft.)	(sq. in.)	(lbs.)	(lbs.)	(lbs.)	(lbs./sq.in.)	(lbs./sq.in.)
3,6&7	Haydite	4.0x7.8x15.9	3	17.2	11.62–22.00	16.05	64.1	48,330	754	617–1047		
		8.2x7.7x15.9**	3	34.7	10.23–11.73	10.87	129.9	131,550	1014	771–1298		
		8.1x7.7x15.9*	3	31.0	9.06–11.58	10.44	128.8	125,270	972	837–1320		
		8.1x7.7x 7.9*	1	18.5			63.8	68,430	1073	910–1198	1569	1019–2417
		11.8x7.8x15.9**	3	44.3	5.81–10.26	8.97	187.8	175,640	935	796–1126		
		11.8x7.8x15.9*	3	44.4	8.92–9.41	9.16	187.2	217,240	1159	1044–1263		
		11.8x7.8x 7.9*	1	22.0			93.1	63,430	682	576– 916		

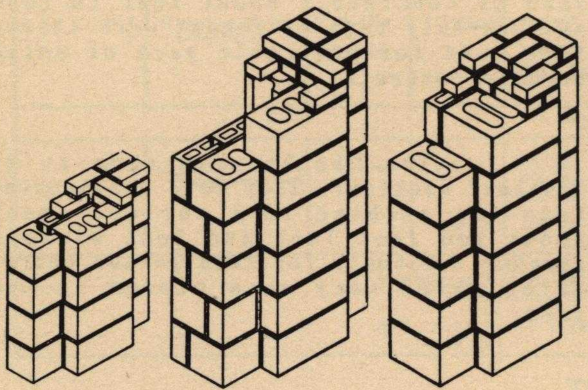
* Only one end of blocks were plane.
** Both ends of blocks were plane.
NOTE: The values for absorption in pounds per cubic foot may be transferred into per cent by dividing by 62.4 pounds per cubic foot, and multiplying by 100.

Table XXIV

PIER NO.	AGGREGATE MATERIALS	BEARING PLATE SIZE	HEIGHT OF PIER	ULTIMATE LOAD TOTAL	UNIT	LATERAL DEFLECTIONS IN 10 FT. HEIGHT AT DESIGN LOAD (90 LBS.)	AT 80% ULT. LOAD	VERTICAL DEFLECTIONS AT 80% OF ULT. LOAD 10 FT. OF HEIGHT	MODULI OF ELASTICITIES (LBS./SQ.IN.) FROM STRAIN GAGE MEASUREMENTS AT BOTTOM	FROM VERTICAL DEFLECTIONS ON BEARING PLATE AREA	FACTOR OF SAFETY*
		(in.)	(ft.)	(lbs.)	(lbs./sq.in.)	(in.)	(in.)	(in.)			
3	Haydite	12x16	10	108,450	565	0.038	0.103	0.093	938,000	538,000	6.28
6	Haydite	16x16	14	132,000	516	0.033	0.108	0.122	725,000	406,000	5.73
7	Haydite	16x16	14	108,850	425	0.027	0.073	0.077	833,000	529,000	4.71

* Based on unit design load of 90 lbs./sq. in.

Table XV



Pier No.3 Pier No.6 Pier No.7

Fig. 30

A mortar composed of one part by volume of portland cement to 3 parts of Zanesville sand, tempered with 10% of hydrated lime, was used in laying up the piers. The physical properties of the blocks are shown in Table XXIV.

The behavior of the units under tests is set out in Table XXV.

The values shown for unit breaking load were obtained by dividing the total breaking load by the area of the bearing plate and are, therefore, assumed equal to the average unit stresses under the bearing plates. Attention is called to the special nature of the loading. Since the loading plate was progressively inclined up to working load, a varying eccentricity of loading resulted. The unit stresses were, therefore, quite varied and a maximum occurred at the edge of the pilaster projection. It is reported that the amount that this maximum exceeded the average depended upon the elastic and plastic properties of the masonry.

The lateral deflections are given for working loads and at 80 per cent of the ultimate loads. It was found to be impossible to continue the lateral deflection readings right up to the breaking load. The author's comment on load calculations follows:

"Eighty per cent of the working load was chosen as it was practicable to obtain good readings at this loading by interpolating from plotted curves. The results shown for the 14-foot piers are reduced to equivalents for 10-foot piers by direct ratio of the heights. The recorded values are each ten-fourteenths of that observed. This ratio was found to be very close to the mean between that of the ordinates for Euler's curve for free ended columns and that for fixed ends."

Conclusions from the test are as follows:

"1. The ultimate strength of the masonry is about one-half of that of the unit. The individual percentages are as follows: Cinder block, 63 and 41 per cent. Gravel block, 44 and 59 per cent. Haydite block, 56, 51 and 45 per cent. The average is 51 per cent.

"2. The maximum unit stresses under the bearing plate at working load and full beam deflection are about four times the average working stress over the entire plate. The individual ratios for points on the piers where the unit stresses are somewhat less than the maximum are as follows: Cinder block, 2.83 and 6.12. Gravel block, 3.26 and 3.23. Haydite block 3.30, 3.32 and 4.01. The average is 3.73.

"3. The factors of safety based upon the ultimate unit strengths and the allowable working stress of 90 pounds per square inch are as follows: Cinder block, 4.29 and 2.74, averaging 3.51. Gravel block, 6.35 and 8.52, averaging 7.43. Haydite block, 6.28, 5.73 and 4.71 averaging 5.57.

"4. A 1:3 Portland cement mortar tempered with 10 per cent of Hydrated lime is sufficiently strong for Portland cement concrete block masonry.

"5. The lateral deflections at working loads are not of serious consequence. The maximum was 0.038 inch in 120 inches or 0.114 of an inch in 360 inches which is only a little over one-tenth of the 1:360 allowable in beams. The average was 0.075 inch in 360 inches. The lateral deflections above working loads did not increase in proportion to that below. The maximum at 80 per cent of the working load was 0.369 inch in 360 inches. The lateral deflections were independent of the moduli of elasticity.

"6. The internal bending due to the eccentric loadings extends down into the piers for distances proportional to the moduli of elasticity. In other words, those piers that had the lowest moduli of elasticity absorbed the bending due to the eccentric leadings in the shortest distance from the load.

"7. Special shapes such as those used in pier No. 7 are inferior to the standard block shape in producing pier strength.

"8. The wing walls (wall sections adjacent to pilasters) at working loads may be depended upon to take up their share of the bending throughout the entire length of the pier and 80 per cent of their share of the compression load at the mid-height. The larger piers took a larger proportion of the load at mid-height than the smaller ones. It takes about seven feet of height to bring the wing walls into full service."

RAIN RESISTANCE

The paper "Tests of the Resistance to Rain Penetration of Walls Built of Masonry and Concrete" by R. E. Copeland and C. C. Carlson, published in the A.C.I. Journal Nov. 1939 and read before the A.C.I. convention in Chicago, March 1940, reported a continuation of a test described by a paper of similar name published in the A.C.I. Journal, March 1936.

The paper is a summary of the entire study embracing over 200 permeability tests conducted for the purpose of developing information on the resistance of various wall construction to wind-driven rain. The details of the aggregate, mixes and physical properties of the Haydite units of the test are given in Table XXVI.

DETAILS OF AGGREGATES, MIXES AND PHYSICAL PROPERTIES OF CONCRETE MASONRY UNITS; SERIES A, B, C, D, J, AND H

AGGREGATE				CONCRETE			
Wall Code No.	Type	Max. Size; Inches	Fineness Modulus	Mix, By Dry Rodded Aggregate Volume	Comp. Strength on Gross Area; p.s.i. (1)	Absorption 24 Hr. Immersion: % of Dry Weight	Absorption 24 Hr. Immersion: % of Volume
Series A and B Walls; 8 by 8 by 16 inch 3 oval core, 32.3% Core Space Block							
AH-1	Haydite	3/8	3.5	1-7	1390	18.2	20.6
AH-2	"	"	3.5	1-9	1120	18.8	20.7
AH-3	"	"	3.5	1-11	1100	20.6	22.7
AH-4	"	5/8	4.5	1-7	1220	15.6	17.2
AH-5	"	"	4.5	1-9	1370	15.8	17.6
AH-6	"	"	4.5	1-11	1110	15.5	15.8
BH-7	"	3/8	4.0	1-9	1150	16.9	18.1
AH-8 (2)	"	"	3.5	1-9	1240	17.8	20.1
AH-9 (2)	"	5/8	4.5	1-9	1030	14.7	16.3
Series C Walls; 4 by 8 by 16 inch 3 core, 24.3% Core Space Tile							
CH-1	Haydite	3/8	3.5	1-7	1050	17.9	19.6
CH-2	"	"	3.5	1-9	890	19.9	20.8
CH-3	"	"	3.5	1-11	830	21.5	22.1
CH-4	"	"	4.25	1-7	900	15.6	16.0
CH-5	"	"	4.25	1-9	900	15.5	14.9
CH-6	"	"	4.25	1-11	730	17.5	16.6
Series D, J and H Walls; 8 by 8 by 16 inch 3 oval core, 36.5% Core Space Block							
J-2	Haydite	1/2	3.75	1-9	1740	15.1	21.0

NOTES:
(1) All specimens air dry when tested. Age of specimens at test: Series A, B, C, J and H, 3 to 6 months; Series D, 28 days.
(2) Oscillated face block -- 40% core space.
(3) Water eroded face block used in walls AS-5, AS-6, AS-7 and AS-8 of same composition as AS-1, AS-2, AS-3, and AS-4 respectively.
(4) Pulverized silica substituted for 30 per cent of the cement.
(5) Purchased from commercial stocks.
Curing: J Series block cured in high pressure steam (350°F.), all others cured 24 hours in steam vapor followed by air storage except AC-8, AC-9, AH-8, and AH-9, which had 3 days damp curing followed by storage in air.

Table XXVI

The following five paragraphs, extracted from the publication, more completely explain the procedure and assumption than could be explained by any attempt of summarizing or re-writing:

The wind and rain duct was placed at a 45 degree angle with the wall face because of the practical necessity of diverting the rebounded rain away from the wall and apparatus. Then too, it appeared that natural rainstorms usually impinge angularly with the wall face due to the natural shifting of the wind and directional interference caused by adjacent structures, trees and topographical irregularities.

EXCELLENT PERFORMANCE
GROUPS WHICH ON THE AVERAGE DEVELOPED NO FLUID LEAKS OR BACK FACE DAMPNESS IN 24 HOURS OF TESTING.

- PAINTED CONCRETE MASONRY WALLS
  THE PAINT COATINGS OF WHICH WERE THOROUGHLY APPLIED WITH STIFF BRISTLE BRUSH TO FORM A CONTINUOUS FILM FREE FROM VOIDS OR SIGNIFICANT CRAZING.
- CONCRETE MASONRY
  WITH THREE COATS PORTLAND CEMENT STUCCO.
- CAST-IN-PLACE CONCRETE WALLS.
- EIGHT-INCH SOLID FACE BRICK WALLS
  BUILT WITH EXCELLENT WORKMANSHIP AND CLASS A MORTAR.
- TWELVE-INCH FACE BRICK WALLS
  WITH EITHER SOLID BRICK OR CONCRETE MASONRY BACK-UP BUILT WITH EXCELLENT WORKMANSHIP.

GOOD PERFORMANCE
GROUPS WHICH ON THE AVERAGE DEVELOPED NO FLUID LEAKAGE AND A DAMPENING OF LESS THAN 25 PER CENT OF THE BACK FACE IN 24 HOURS OF TESTING.

- EIGHT-INCH SOLID FACE BRICK WALLS
  BUILT WITH AVERAGE WORKMANSHIP AND CLASS A MORTAR OR WITH EXCELLENT WORKMANSHIP AND CLASS B MORTAR.
- PAINTED CONCRETE MASONRY WALLS,
  THE PAINT COATINGS OF WHICH HAD DEVELOPED SUPERFICIAL CRAZING DUE TO NORMAL SHRINKAGE EFFECTS.

FAIR PERFORMANCE
GROUPS WHICH ON THE AVERAGE DEVELOPED NOT MORE THAN 15 LB. OF FLUID LEAKAGE NOR A DAMPENING OF MORE THAN 50 PER CENT OF THE BACK FACE IN 24 HOURS OF TESTING.

- EIGHT-INCH SOLID FACE BRICK WALLS
  BUILT WITH AVERAGE WORKMANSHIP AND CLASS B MORTAR OR WITH EXCELLENT WORKMANSHIP AND CLASS C MORTAR.
- EIGHT-INCH WALLS OF 2-IN. FACE BRICK AND 6-IN. CONCRETE MASONRY BACK-UP
  BUILT WITH THROUGH HEADER COURSES (NO HEADER BLOCK).
- SPRAY PAINTED CONCRETE MASONRY WALLS,
  THE COATINGS OF WHICH CONTAINED MINUTE PINHOLES.
- EIGHT-INCH SOLID SELECT COMMON BRICK WALLS
  BUILT WITH EXCELLENT WORKMANSHIP AND CLASS B OR BETTER MORTAR.
- TWELVE-INCH WALLS OF 4-IN. FACE BRICK PLUS 8-IN. COMMON BRICK OR CONCRETE MASONRY BACK-UP
  BUILT WITH AVERAGE WORKMANSHIP AND CLASS B MORTAR.

POOR PERFORMANCE
GROUPS WHICH ON THE AVERAGE DEVELOPED FROM 15 TO 50 LB. FLUID LEAKAGE AND/OR A DAMPENING OF 50 TO 75 PER CENT OF THE BACK FACE IN THE 24-HOUR TEST.

- PAINTED CINDER BLOCK WALLS,
  THE PAINT COATINGS OF WHICH WERE BADLY CRAZED DUE TO EXCESSIVE EXPANSION OF THE CINDER CONCRETE.
- EIGHT-INCH SELECT COMMON BRICK WALLS
  BUILT WITH EXCELLENT WORKMANSHIP AND CLASS C MORTAR.

VERY POOR PERFORMANCE
THE PERFORMANCE OF THE FOLLOWING GROUPS WAS CHARACTERIZED BY RAPID PENETRATION RESULTING IN FLUID LEAKAGE OF OVER 50 LB. AND USUALLY A GENERAL DAMPENING OF THE BACK FACE.

- CONCRETE MASONRY WALLS
  UNPAINTED OR TREATED WITH THIN-BODIED LIQUID WATERPROOFINGS OF THE PENETRATIVE TYPE.
- EIGHT-INCH SOLID COMMON BRICK WALLS
  BUILT WITH AVERAGE WORKMANSHIP.
- EIGHT-INCH WALLS OF 4-IN. FACE BRICK AND 4-IN. CINDER TILE BACK-UP
  BUILT WITH AVERAGE WORKMANSHIP.
- EIGHT-INCH WALLS OF 2-IN. FACE BRICK AND 6-IN. CONCRETE MASONRY BACK-UP
  BUILT WITH HEADER BLOCK AT HEADER COURSES AND WITH NO PROVISIONS TO RETARD THE DOWNWARD DRAINAGE OF MOISTURE IN THE CORE SPACES.

Fig. 31

The selection of a 25 m.p.h. wind velocity as standard in these tests was based on a rather comprehensive survey of climatic data pertaining to the following cities: Chicago, Cleveland, St. Louis, New York, Washington, Jacksonville, Florida, Galveston, Texas, New Orleans and Miami. The records studied covered all rains of 1 in. or more in 24 hours which occurred during the 12 to 20-year period ended in 1935. These data showed that of the total of 1,759 such rains all but 36 were accompanied by winds whose velocity averaged less than 25 m.p.h.

Concerning the duration of rainstorms, the records showed that continuous rainfall seldom exceeds 24 hours but that intermittent rainfall (with less than 8 hours' cessation) sometimes lasts for two to four days. Invariably, however, the longer rains are of much lighter intensity. Intensities exceeding 1 in. per hour seldom last for more than a few hours. Series G test results indicated that the 24 hour test with 2-1/2 in. rain intensity is equivalent to a much longer period with a 1/2-in. rain.

The test exposure first employed in series A consisted of 24 hours with a 25 m.p.h. wind and 2-1/2-in. rain intensity. The unpainted concrete masonry walls developed appreciable leakage well within the 24-hour period. However, in testing the painted walls in this series very little penetration was obtained. Therefore, the cycle was changed to 12 hours with 2-1/2-in. rain intensity and 25 m.p.h. wind immediately followed by another 12 hours with 12-in. rain intensity and 25 m.p.h. wind. This cycle was employed in testing all painted concrete masonry walls and for series F, F1, F2, H and J. Some of the tests in series F3 were of longer duration and in Series G different combinations of rain and wind intensity were employed.

The rain intensities employed in the tests are expressed in inches of water per hour striking against the vertical face of the specimen; that is, they are equivalent to the depth of water which, if allowed to remain, would accumulate in one hour on the wall face. They are not necessarily equivalent to natural rainfalls of the same intensity as these are customarily measured and expressed in inches of water falling on a horizontal surface. The relation which the intensity on a vertical surface bears to that on a horizontal surface depends upon the vertical angle at which the rain falls as determined by the velocity of the wind and other factors.

The author's summary of the tests is constructed in semigraphical form in Figure 31 and the results of the Haydite units are given in Table XXVII.

Wall Code No.	Unit Details: Dry Rodded Mix by Volume	Unit Details: Fineness Modulus	Mortar Used in Wall	Endurance Periods of Walls — Unpainted: Minutes	Unpainted: Back Face Observation on Wetting	Painted: Hrs.	Painted: Back Face Observation
AH 1	1-7	3.5	1-1-6	25	50% damp	24+	Dry
2	1-9	"	"	20	" "	24+	"
3	1-11	"	"	25	" "	24+	"
4	1-7	4.5	"	15	" "	24+	"
5	1-9	"	"	25	dis.	24+	"
6	1-11	"	"	45	dis.	24+	"
BH7A	1-9	4.0	"	28	50% damp	20½ [1]	Dis.
B	"	"	1-3P+1/4L	12	50% "	24+	Dry
C	"	"	1-3L	20	60% "	-	-
D	"	"	1-3L	18	60% "	3½ [2]	25% damp
E	"	"	1-1-6	22	75% "	24+	Dry
F	"	"	"	15	60% "	-	-
AH 8	1-9	3.5	"	107	Jd.	24+	Dry
9	1-9	4.5	"	60	dis.	24+	Dry
CH 1	1-7	3.5	"	5	75% damp	22¼	Jd.
2	1-9	"	"	5	80% "	24+	Jd.
3	1-11	"	"	5	80% "	21½	Jd.
4	1-7	4.25	"	10	75% "	24	Jd.
5	1-9	"	"	10	65% "	24+	Jd.
6	1-11	"	"	7	65% "	24+	Jd.

1 Wall Painted with 3 spray coats
2 Wall Painted with 2 spray coats
dis. = Damp in spots
Jd. = Joints damp

A & B Reference Nos. 8" Walls
C " " 4" Walls

Table XXVII

DEPARTMENT OF COMMERCE TESTS

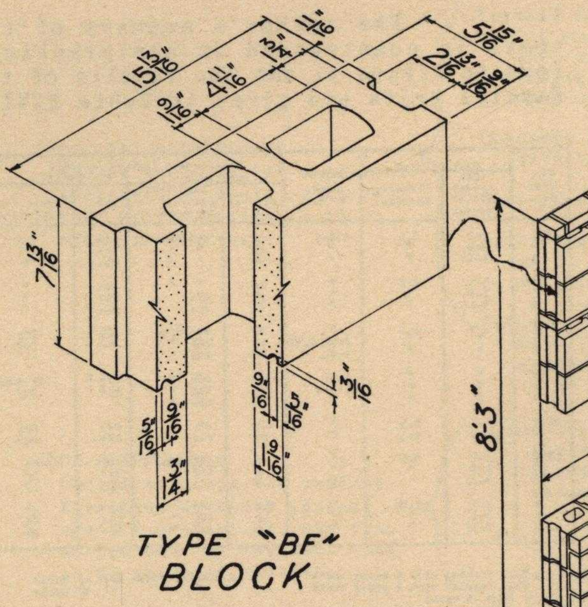
Congress included the sum of $198,000, in the appropriation for the National Bureau of Standards for the fiscal year beginning 1937, for a program on "Research on Building Materials and Structures for Use in Low Cost Housing". The general object was stated:

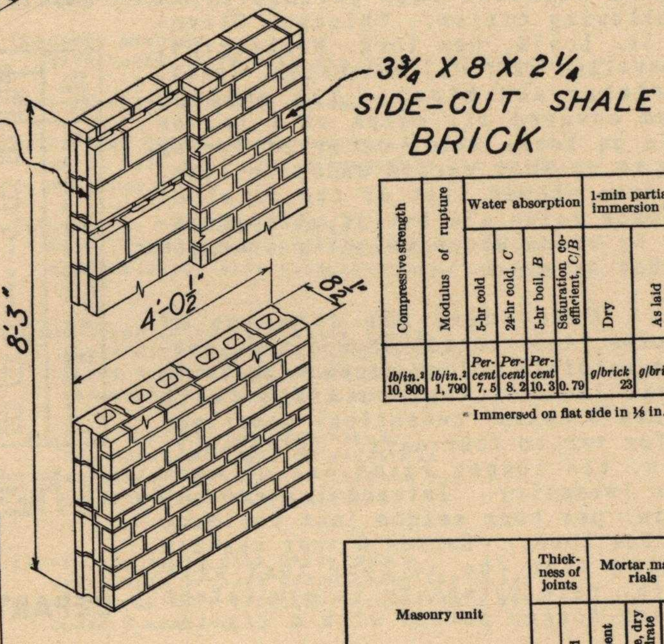
"To furnish to government agencies, the building industry, and the public, technical information from every available source on the engineering properties of building materials as incorporated in the structural elements of a house with particular reference to low cost housing and including new materials, equipment and methods of construction as well as those already in use".

Certain maximum costs of the elements of a house were set up that are of sufficient interest to repeat here:

Structural Elements	Maximum Cost p.s.f.
Walls	60 cents
Partitions, not load bearing	35
Floors, including finished floors on upper face and ceiling (if any) on lower face	75
Roofs, including water proof on upper roof and ceiling (if any) on lower face	60

In order to cooperate to the fullest extent specimens for one or more structural elements of a house were





Compressive strength	Modulus of rupture	Water absorption				1-min partial immersion [a]		Weight, dry
		5-hr cold	24-hr cold, C	5-hr boil, B	Saturation coefficient, C/B	Dry	As laid	
lb/in.²	lb/in.²	Per-cent	Per-cent	Per-cent		g/brick	g/brick	lb/brick
10,800	1,790	7.5	8.2	10.3	0.79	23	15	5.06

[a] Immersed on flat side in ⅛ in. of water.

Concrete unit	Thickness of face shell, minimum	Modulus of rupture	Compressive strength, gross area	Water absorption by total immersion, 24-hr. cold		Weight, dry	
	in.	lb/in.²	lb/in.²	Percent, by weight	lb/ft³ of concrete	lb/unit	lb/ft³ of concrete
"Haydite" full-sized block	1.56		1,440	14.5	12.4	25.6	88.1
"Haydite" half block	1.55			14.5	12.1	12.4	87.4
"Haydite" brick		385	1,670	13.6		3.0	

Masonry unit		Thickness of joints		Mortar materials			Mason's time
		Bed	Head	Cement	Lime, dry hydrate	Sand, dry	
	Number/ft²	in.	in.	lb/ft²	lb/ft²	lb/ft²	hr/ft²
Brick	[a] 4.31	0.56	0.49	1.85	0.78	9.44	0.12
"Haydite" block	[a] 0.90	.64	.52				
"Haydite" brick	.90						

[a] For walls containing 25 facing courses.

Fig. 32

solicited for inclusion in the program. Thru the sponsorship of the N.C.M.A. numerous wall designs were submitted, one of which, Figure 32, represents a "brick-concrete-block wall" construction with a facing of rowlock brick (laid on edge) and a backing of Haydite-concrete blocks.

The expense of the test was borne by the Bureau of Standards but the material was furnished and the wall constructed by the sponsoring agent at the N.B.S. laboratory in preparation for the test. The necessary expense for producing this wall was borne by the National Concrete Masonry Association, the Haydite Manufacturers Association, the American Aggregate Company and the John H. Black Company. Both the brick and blocks were produced at the plant of the John H. Black Company.

The blocks were produced on an Anchor machine and the design gave yield of approximately 22 blocks per sack of cement. The average dimensions of the full-sized blocks were 5.95 by 15.80 by 7.84 in. (about 5-15/16 by 15-13/16 by 7-13/16 in.) and of the half blocks 5.95 by 7.71 by 7.82 in. (about 5-15/16 by 7-11/16 by 7-13/16 in.) The average dimensions of the Haydite brick were 3.86 by 8.00 by 2.21 in. (about 3-7/8 by 8 by 2-3/16 in.).

The brick were side-cut shale, with textured edges and ends, with the average dimension 3.7 x 8 x 2.25 in.

The physical properties of the brick and masonry units, in addition to the fabrication data, are shown in tabular form in Figure 32. The values per sq. ft. were computed using the face area of the specimens.

Cumulative retained percentage of the combined aggregate and cumulative percentage of the Sand composing the mortar are shown in Figure 33. The mortar was 1 part cement, 0.42 parts of hydrated lime, and 5.1 parts of dry sand, by weight. The proportions by volume were 1:1:6..

Tests were begun on September 12, 1938 and completed February 10, 1939 and the results published in Department of Commerce Building Materials and Structures report BMS32.

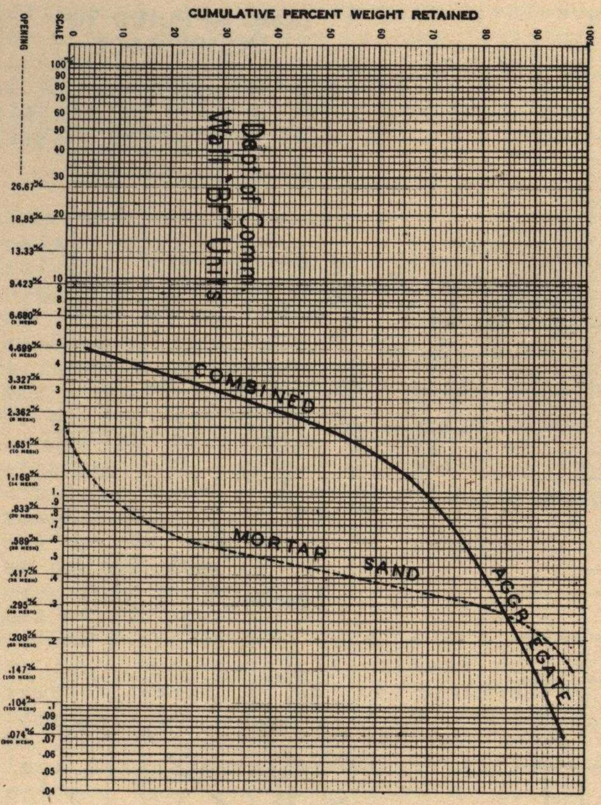


Fig. 33

The specimens were built with a brick facing and a backing of Haydite concrete units with cement-lime mortar. In order to increase the height of the transverse and impact specimens, they were built with a bonding course at the upper end. Including the top stretcher course, there were 25 courses of brick in the facing and 15 courses of Haydite concrete units in the backing. The facing consisted of rowlock stretcher courses (brick laid on edge), bonded at every fifth course by a stretcher course of brick laid on the flat side. Two courses of Haydite concrete blocks were used as a backing for every four courses of facing rowlock stretchers. The brick bonding course was backed by a stretcher course of Haydite concrete brick. The 4-ft. wall specimens were 8 ft. 3 in. high, 4 ft. 1/2 in. wide, and 8-1/2 in. thick, except for the compressive specimens which were 8 ft. 1/2 in. high. The 8-ft. wall specimens were 8 ft. 1/2 in. high, 8 ft. 1-1/2 in. wide, and 8-1/2 in. thick.

The bed joints of the facing were furrowed slightly and all the head joints were filled. The mortar in the bed joints of the Haydite concrete blocks were laid under the back and face shells only. The head joints in the face were buttered with mortar, whereas the inner head joints were left open. The collar joint between facing and backing was not filled.

The price of this construction in Washington D. C., as of July 1938, was $0.41 per square foot.

"The cost of this construction is less than that of the conventional brick-faced wall because less brick is required. For an 8-in. wall the backing unit is 6 in. thick, and for a 12-in. wall the backing unit is 10 in. thick. Time studies indicate that the labor cost for walls of this construction is somewhat less than for conventional brick-faced walls. It is recommended not only for low-cost houses but especially for churches, schools, and industrial buildings."

Under the program, walls and load-bearing partitions were subjected to COMPRESSIVE, TRANSVERSE, CONCENTRATED, IMPACT and RACKING loads, in the laboratory. In actual service, house walls are subjected to vertical COMPRESSIVE LOADS by the dead weight of the walls, floor, and roof above, and by the live loads above (wind, and the weight of snow on the roof, furniture, or persons on the floor, etc.) HORIZONTAL TRANSVERSE (bending) loads, caused by wind, act upon the outside faces of such walls, and sometimes upon their inside faces on the leeward side.

Walls may also be subjected to CONCENTRATED loads (large forces over a small area, such as a ladder placed against either face). IMPACT loads may be applied accidentally to a wall, for example, by a coal truck backing against the outside, or by a person or bookcase falling against the inside face of the wall. CONCENTRATED and IMPACT loads come under the head of abuse, and, to a considerable extent, are unavoidable under service conditions. RACKING (shearing) LOADS are applied to a wall by intersecting walls against which a wind is blowing.

A detailed method of conducting such tests has been published in "Department of Commerce Building Materials and Structures report, BMS2." In the complete report of the tests on the brick-Haydite building unit walls (BMS32) the behavior under each type of loading for the individual wall is fully explained. Figure 34 shows graphically the effect of the loading at various periods. Throughout these diagrams the effect of load shortening, load lateral deflection, load indention, and load-

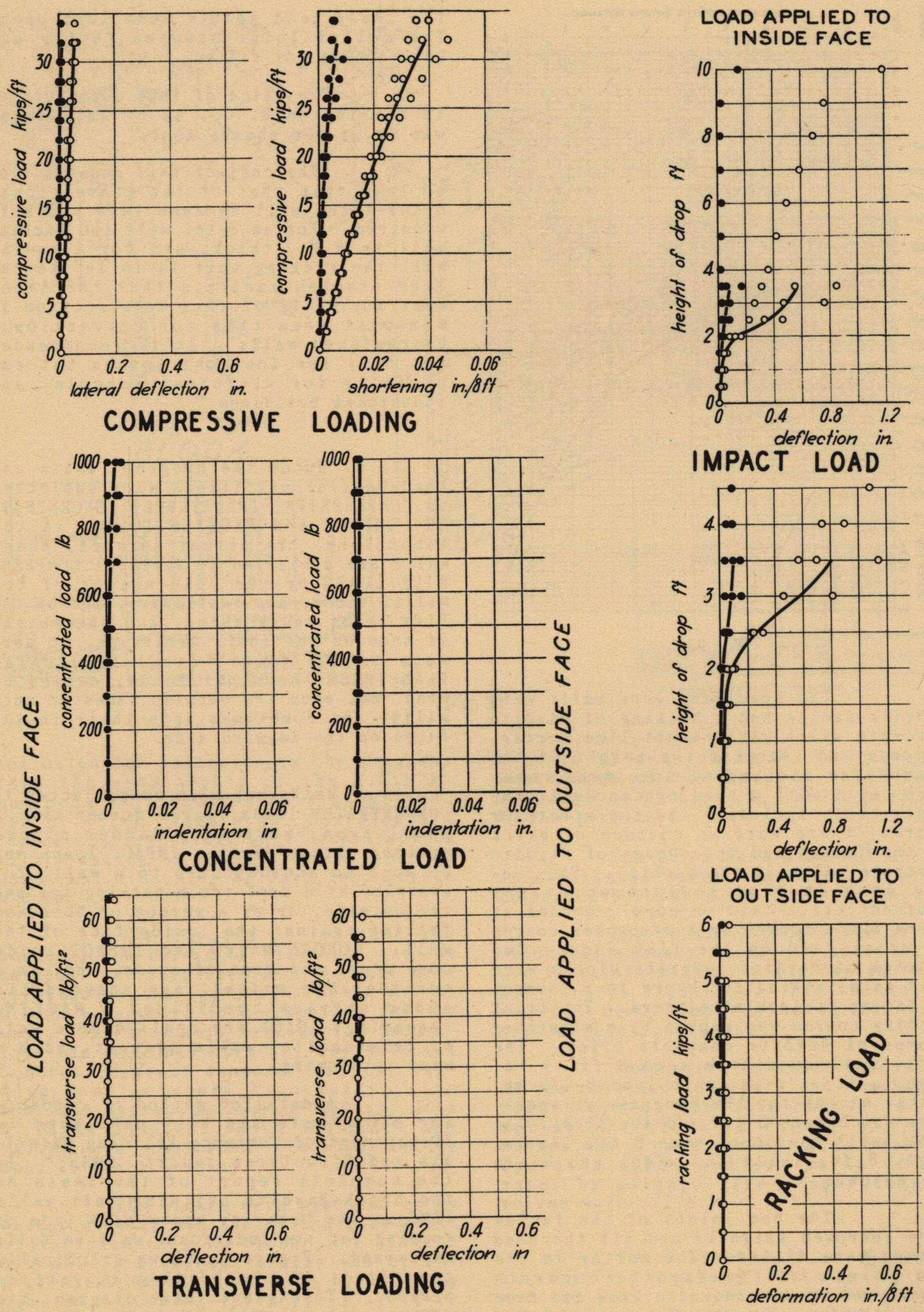
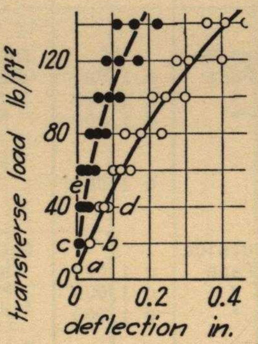

compressive load kips/ft
lateral deflection in.
compressive load kips/ft
shortening in./8ft
COMPRESSIVE LOADING
LOAD APPLIED TO INSIDE FACE
height of drop ft
deflection in.
IMPACT LOAD
height of drop ft
deflection in.
LOAD APPLIED TO OUTSIDE FACE
LOAD APPLIED TO INSIDE FACE
concentrated load lb
indentation in
concentrated load lb
indentation in.
LOAD APPLIED TO OUTSIDE FACE
CONCENTRATED LOAD
transverse load lb/ft²
deflection in.
transverse load lb/ft²
deflection in
TRANSVERSE LOADING
racking load kips/ft
deformation in./8ft
RACKING LOAD

Fig. 34

deflection, is shown by open circles. The effect of load set in each instance is shown by solid circles. This method of designation is probably better explained by the following quotation and diagram taken from BMS2:

"For all tests the loads are plotted as ordinates and the deformations as abscissas. For all specimens the load is applied in increments so chosen that a sufficient number of readings is obtained to determine definitely the load-deformation curve. The initial reading of the load and the reading of the deformation is recorded either with no load on the specimen or under a small initial load as at a, figure 18. The load is increased to the first increment, b, and the deformation recorded. The load is then decreased to the initial load, a, and the set (sometimes designated 'permanent set') recorded. This set is plotted at c, the ordinate being the load which, when released, caused this set. The load is then increased to two increments, d, and the set when it is released to the initial load, a, plotted at e. This sequence of readings and points on the graph is then followed for three increments, four increments, etc. of load. There are three duplicate specimens for each test and the results for each specimen are shown on the same graph. Although the particular specimen for each point on the graph is not designated, they were recorded on the laboratory data sheets. The points for deformation under load are shown by open circles and those for set by solid circles. The three values for either the deformation or the set are averaged and this average value plotted in pencil on the graph. A smooth curve is drawn among the average points to show the average behavior of the construction. The load-deformation curves are continuous lines and the load-set curves are dashed lines. If readings are obtained under greater loads for some specimens than for others, all the values are plotted, but the curves are only drawn to the average values for each specimen the behavior of the specimen under load indicates that the specimen might fail suddenly and damage the deformation-measuring apparatus, this apparatus is removed from the specimen and the load increased continuously until the maximum load which can be applied to the specimen is determined. The maximum loads are not plotted on the graph but are given in the report. This method of testing by applying the loads in increments and measuring the deformation, then the set under the initial load, simulates, to some extent, repeated loading under service conditions. Therefore, results by such a method of loading may be more useful than those obtained by increasing the load continuously. They may show whether different portions of a construction act as a unit under load, whether the fastenings or bonds have adequate strength, or whether they rupture under repeated loads."



The maximum loads, not recorded on the diagrams, are shown in Table XXVIII.

THERMAL PROPERTIES

Values obtained from the numerous tests conducted to determine the coefficients of heat conductivity for Haydite units and Haydite concrete vary to some extent. This variation is undoubtedly the result of the physical properties, composition, grading and texture of the units or materials submitted for test. However, there is not sufficient variation in any of the determinations to effect practical calculations materially.

The results of experiments by the Hydraulic-Press Brick Company at their laboratory and in commercial laboratories on products submitted by them are shown in Table XXIX.

Tests were conducted at the University of Minnesota as a cooperative research sponsored by the American Society of Heating and Ventilating Engineers in cooperation with the Portland Cement Association and published as the article "Thermal Properties of Concrete Construction" which appeared in the Jan. 1936 issue of Heating, Piping and Air-conditioning (Journal A.S.H.V.E.). The physical properties, construction data and behavior of Haydite masonry unit construction in this test are shown in Table XXX. The aggregate grading, concrete proportions and behavior of the monolithic Haydite concrete walls are shown in Table XXXI.

The A.S.H.V.E. values for the coefficient of heat transmission factors "C", "U", and "U corrected to 15 mile velocity", were determined by the construction and testing of 22 walls, 14 of which were composed of cinder masonry units. Factors were obtained on the

LOAD

WEIGHT BASED ON FACE AREA	COMPRESSIVE [a]	TRANSVERSE [b]		CONCENTRATED		IMPACT [b]		RACKING
	Maximum load	Load Appl'd. To	Maximum load	Load Appl'd. To	Maximum load	Load Appl'd. To	Maximum height of drop	Maximum load
Lb/sq. ft.	Kips/ft.	Inside Face	Lb/sq.ft.	Inside Face	lb.	Inside Face	ft.	Kips/ft.
60.9	34.0		67.1		d 1,000		3.5	6.03
"	45.2	"	45.9	"	d 1,000	"	3.5	5.19
"	47.3	"	56.7	"	d 1,000	"	10.0	d 6.15
Average	42.1		56.6		d 1,000		5.7	
		Outside Face	40.0	Outside Face	d 1,000	Outside Face	4.5	
		"	60.0	"	d 1,000	"	3.5	
		"	48.0	"	d 1,000	"	4.0	
Average			49.3		d 1,000		4.0	

a - Load applied at one-third thickness of specimen from inside face.
b - Span 7 ft. gin.
d - Test discontinued specimen did not fail.

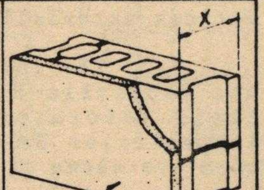
Table XXVIII

COEFFICIENTS OF TRANSMISSION (U) OF HAYDITE BUILDING UNITS WITH 1" STUCCO EXTERIOR.

NOTE. THESE COEFFICIENTS ARE EXPRESSED IN B.T.U. PER HOUR PER SQUARE FOOT PER 1 DEG. FAHR. DIFFERENCE IN TEMPERATURE BETWEEN THE AIR ON THE TWO SIDES AND ARE BASED ON AN OUTSIDE WIND EXPOSURE OF 15 MILES PER HOUR.

THE VALUES OF U IN THIS TABLE ARE BASED ON THE FOLLOWING INTERNAL CONDUCTIVITIES OR CONDUCTANCES WHICH ARE EXPRESSED IN B.T.U PER HR. PER SQ. FT PER 1°F.

HAYDITE UNITS 4"	0.66	
HAYDITE UNITS 8"	0.30	
HAYDITE UNITS 12"	0.20	EST.
STUCCO	8.00	PER 1"
CEMENT MORTAR	8.00	PER 1"
HAYDITE MORTAR	3.98	PER 1"
PLASTER (GYPSUM)	2.32	PER 1"
WOOD LATH + PLASTER	2.00	AS APP.
PLASTER BOARD	3.73	PER ⅜"
AIR SPACE (½" OR OVER)	1.10	



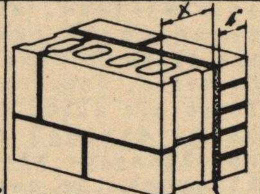
NUMBER	INTERIOR CONSTRUCTION	THICKNESS OF HAYDITE UNITS - X	
		8" UNIT	12" UNIT
		A	B
1	PLAIN WALLS NO INTERIOR FINISH	0.225	0.163
2	½" PLASTER ON UNITS	0.214	0.158
3	¾" PLASTER ON METAL LATH - FURRED	0.177	0.136
4	½" PLASTER ON WOOD LATH - FURRED	0.170	0.133
5	½" PLASTER ON ⅜" PLASTERBOARD - FURRED	0.171	0.134

COEFFICIENTS OF TRANSMISSION (U) OF HAYDITE BUILDING UNITS WITH 4" BRICK EXTERIOR

NOTE THESE COEFFICIENTS ARE EXPRESSED IN B.T.U. PER HOUR PER SQUARE FOOT PER 1 DEG. FAHR. DIFFERENCE IN TEMPERATURE BETWEEN THE AIR ON THE TWO SIDES AND ARE BASED ON AN OUTSIDE WIND EXPOSURE OF 15 MILES PER HOUR.

THE VALUES OF U IN THIS TABLE ARE BASED ON THE FOLLOWING INTERNAL CONDUCTIVITIES OR CONDUCTANCES WHICH ARE EXPRESSED IN B.T.U. PER HR. PER SQ. FT. PER 1°F.

HAYDITE UNITS 4"	0.66	
HAYDITE UNITS 8"	0.30	
HAYDITE UNITS 12"	0.20	EST.
BRICK	5.00	PER 1"
CEMENT MORTAR	8.00	PER 1"
HAYDITE MORTAR	3.98	PER 1"
PLASTER (GYPSUM)	2.32	PER 1"
WOOD LATH + PLASTER	2.00	AS. APP.
PLASTER BOARD	3.73	PER ⅜"
AIR SPACE (½" OR OVER)	1.10	



NUMBER	INTERIOR CONSTRUCTION	THICKNESS OF HAYDITE UNITS - X	
		8" UNIT	12" UNIT
		A	B
1	PLAIN WALLS NO INTERIOR FINISH	0.199	0.150
2	½" PLASTER ON UNITS	0.191	0.145
3	¾" PLASTER ON METAL LATH - FURRED	0.160	0.127
4	½" PLASTER ON WOOD LATH - FURRED	0.156	0.124
5	½" PLASTER ON ⅜" PLASTERBOARD - FURRED	0.157	0.125

Table XXIX

Wall No.	Type of Aggregate	Description of Block	Density of Material in Blocks Lb/Cu Ft	Percentage of Core Volume	Over-all Thickness of Wall in Inches	Inside Surface Finish	Outside Surface Finish	Additional Insulation in Wall	Density of Insulating Material Lb/Cu Ft	Weight of Insulating Material per Sq Ft of Wall Area Exclusive of Surface Finish	Aggregate Used in Wall Percent by Weight	Fineness Modulus of Aggregate			Dry Rodded Weight of Aggregate Lb per Cu Ft		Mix Proportion Dry Rodded Volume	Water-Cement Ratio W/C Gal/Sack	28 Day Compressive Strength Air Dried					Percent Absorption at 28 Days	
																			Area of Specimen Sq In		Total Breaking Load Lb	Breaking Load Lb/Sq In			
												Fine	Coarse	Combined	Fine	Coarse			Gro	Net		Gro	Net	By Wt	By Vol
2a	Haydite Block	8 in. x 8 in. x 16 in. 3-Oval Core	67.7	39.6	7.91	As Laid	As Laid	None	......	......	100 Percent Haydite 64 Percent Size A	2.76	5.94	3.92	58	43	1:8½	10.82	125.5	75.75	97,780	779	1280	24.4	25.5
2b	Haydite Block	8 in. x 8 in. x 16 in. 3-Oval Core	67.7	39.6	7.91	As Laid	Two Coats Water proofed White Portland Cement Paint	None	......	......	36 Percent Size B by weight	2.76	5.94	3.92	58	43	1:8½	10.82	125.5	75.75	97,780	779	1280	24.4	25.5

Wall No.	Type of Aggregate in Blocks	Aggregate Grading and Average Fineness Modulus	Blocks Manufactured Date	Walls Built Date	Inside Surface Treatment	Date of Treatment	Outside Surface Treatment	Date of Treatment
2a	Haydite	Average Fineness Modulus=3.92 Percent Passing ½ in.—100.0 No. 16— 38.2 ⅜ in.— 93.1 No. 30— 21.9 No. 4— 68.5 No. 50— 14.4 No. 8— 61.7 No. 100— 10.0	11-23-34	1-3-35	None		None	
2b	Haydite		11-23-34	1-3-35	None		2 Coats Water Proofed White Portland Cement Paint	3-16-35

Wall No.	Test No.	Date of Test	Description of Wall	Inside Surface Finish	Outside Surface Finish	Additional Insulation in Walls	Air Temperatures F			Coefficient of Heat Transmission		
							High Side	Low Side	Mean Temp.	C	U	U Corrected to 15 mph Wind Vel.
2a	3	2-14-35	8 in. x 8 in. x 16 in. 3-Oval Core Haydite Block	As laid	As laid	None	80.07	0.0	40.03	0.498	0.305	0.357
2a	11	3-15-35		As laid	As laid	None	79.80	0.20	40.00	0.493	0.303	0.354
2b	16	3-28-35		As laid	Two Coats Water Proofed White Portland Cement Paint	None	80.23	—0.27	39.98	0.454	0.289	0.334

Table XXX

Wall No.	Type of Aggregate	Description of Wall	Density of Concrete in Wall Lb/Cu Ft	Overall Thickness of Wall in Inches	Inside Surface Finish	Outside Surface Finish	Additional Insulation	Density of Insulating Material Lb/Cu Ft	Weight of Insulation per Sq Ft of Wall Area	Aggregate Used in Wall Per Cent by Weight	Fineness Modulus of Aggregate: Fine	Fineness Modulus of Aggregate: Coarse	Fineness Modulus of Aggregate: Combined	Dry Rodded Weight of Aggregate Lb per Cu Ft: Fine	Dry Rodded Weight of Aggregate Lb per Cu Ft: Coarse	Mix Proportion Dry Rodded Volume	Water Cement Ratio W/C Gal per Sack	Average Slump Inches	28 Day Compressive Strength Wet: Area of Cylinder Sq In	28 Day Compressive Strength Wet: Total Breaking Load Lb	28 Day Compressive Strength Wet: Breaking Load in Lb/Sq In	Percent Absorption at 28 Days: By Wgt	Percent Absorption at 28 Days: By Vol
34a	Haydite	Haydite Aggregate Plastic Mix	77.7	3.96	As Cast	As Cast	None	....	....	100 Percent Haydite 42.6 Percent Fine 57.4 Percent Coarse	2.76	6.67	5.00	58.6	44.41	1:2¼:4	10.5	4.87	28.8	64,992	2,252	23.07	28.80

Wall No.	Type of Aggregate in Wall	Grading of Aggregate and Average Fineness Modulus	Mix Proportions by Volume and Kind of Mix	Number of Lifts Required for Pouring Wall	Date of Building Wall
34a	Haydite Concrete	Average Fineness Modulus=5.00 Percent Passing Fine: No. 4—99.9, No. 8—94.8, No. 16—58.2, No. 30—33.3, No. 50—21.5, No. 100—14.7 Coarse: ¾ in.—100.0, ½ in.—88.7, ⅜ in.—38.8, No. 4—5.3, No. 8—0.0	1:2¼:4 Plastic Mix	4	1-11-35

Wall No.	Test No.	Date of Test	Description of Wall	Inside Surface Finish	Outside Surface Finish	Insulation	Air Temperature F: High Side	Air Temperature F: Low Side	Air Temperature F: Mean Temp.	Coefficient of Heat Transmission: C	Coefficient of Heat Transmission: U	Coefficient of Heat Transmission: U Corrected to 15 mph Wind Vel.
34a	25	4-18-35	4 in. Haydite Concrete Plastic Mix	As Cast	As Cast	None	80.21	—0.22	40.00	0.943	0.429	0.540

Wall No.	Description	Conductance C	Thickness Inches	Thermal Conductivity k
30a	4 in. sand and limestone concrete Plastic Mix	2.810	4.318	12.14
31a	4 in. sand and coarse gravel concrete Plastic Mix	2.976	4.168	12.40
32a	4 in. sand and coarse gravel concrete Dry Tamp Mix	3.230	4.050	13.10
33a	4 in. 100 per cent cinder concrete Plastic Mix	1.472	3.902	5.75
34a	4 in. 100 per cent Haydite Plastic Mix	0.943	3.960	3.73
36a	4 in. sand and coarse cinder Dry Tamp Mix	2.160	3.958	8.54

Table XXXI

MASONRY UNITS

Coefficient of Transmission "U" of Concrete Masonry Walls,
Wind Velocity 15 Miles Per Hour.

Basic Wall Construction	INTERIOR FINISH 1/2" Plaster On					
	None	Wall	Wood Lath Furred	Metal Lath Furred	½"rigid Insulation Furred	1"rigid Insulation Furred
8 in. walls						
Hollow Cinder Block	.40	.37	.26	.27	.20	.16
Hollow Concrete Block	.53	.49	.31	.32	.24	.17
Hollow Haydite Block	.36	.34	.24	.25	.19	.15
12 in. walls						
Hollow Cinder Block	.34	.32	.23	.24	.19	.15
Hollow Concrete Block	.48	.45	.30	.31	.23	.17
Hollow Haydite Block	.29	.27	.21	.21	.17	.14
12" walls; 4" Brick, 8" Concrete Masonry						
Hollow Cinder Block Backup	.34	.32	.23	.24	.19	.15
Hollow Concrete Block Backup	.42	.39	.27	.28	.21	.16
Hollow Haydite Block Backup	.31	.30	.22	.23	.18	.14
Granular or loose Fill* placed in cores of Hollow Units (¼ cu.ft. per sq.ft.)						
8 in. walls						
Cinder Block-filled cores	.20	.19	.16	.17	.14	.11
Concrete Block-filled cores	.30	.29	.22	.22	.18	.14
Haydite Block-filled cores	.18	.18	.15	.15	.13	.11
12 in. walls						
Cinder Block-filled cores	.17	.17	.14	.14	.12	.10
Concrete Block-filled cores	.29	.27	.21	.21	.17	.14
Haydite Block-filled cores	.15	.15	.13	.13	.11	.10
12" walls; 4" Brick, 8" Concrete Masonry						
Cinder Block Backup-filled cores	.18	.18	.15	.15	.13	.11
Concrete Block Backup-filled cores	.27	.25	.19	.20	.16	.13
Haydite Block Backup-filled cores	.17	.16	.14	.14	.12	.10

* Regranulated cork, rock or mineral wool, expanded micaceous shale or other suitable materials with similar "k" values.

NOTE: Two coats of Portland Cement paint applied to exterior of 8" plain block walls reduced the heat loss values .02 to .03 B.T.U.

Table XXXII

cinder unit walls under various conditions, as:

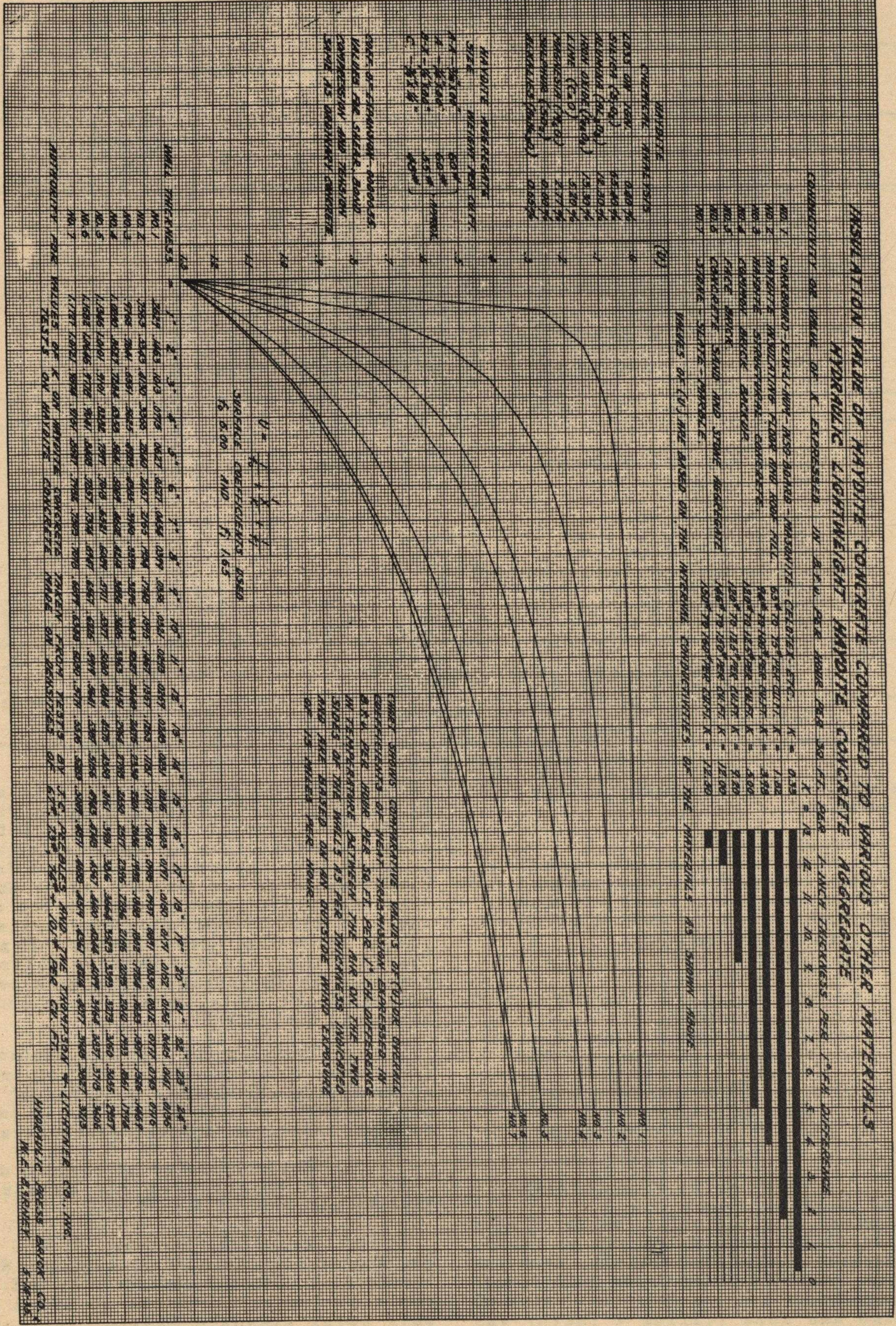
1. Factors for bare wall
2. Factors for wall with inside surface finish
3. Factors for wall with outside surface finish
4. Factors for wall with finish both sides
5. Individual factors for walls of 5 different types of core filling, as:
   (a) Granulated cork
   (b) Rock wool
   (c) Rock wool with 1/2" plaster on metal lath, furred 1"
   (d) Rock wool with 1/2" plaster applied direct and 1/2" insulation board, furred 1"
   (e) Cores filled with dry cinders; "as laid" and plaster "inside finish with "painted outside finish"

Three walls were constructed using Haydite units and the factors determined on these walls "as laid" with no additional insulation and no inside or outside finish. Obviously, from the results on walls constructed with cinder masonry units and the different types of finish and core filling a factor was determined that was believed to be applicable to Haydite masonry walls with different types of finish and insulation. The coefficients, apparently computed by applying a factor obtained from cinder units to the base factor on Haydite units, furnished the values for the table on heat transmission coefficients given in P.C.A. publication (P-26) "Facts About Concrete Masonry Units". Practically identical values were submitted to the contributor and are shown herein as Table XXXII.

Thompson and Lichtner Company, Inc., determined a coefficient of heat conductivity for Haydite concrete of 74 pound density at 1.82 B.T.U. per hr./sq. ft./in. thickness/degree differential.

The University of Toronto determined a coefficient for 90 pound Haydite concrete of 2.24 B.T.U.

Mr. J. C. Peebles, M. E., of the Armour Institute of Technology, determined an internal conductivity B.T.U. per hour for total thickness of an 8" wall using standard 8x8x16" units of


INSULATION VALUE OF HAYDITE CONCRETE COMPARED TO VARIOUS OTHER MATERIALS
HYDRAULIC LIGHTWEIGHT HAYDITE CONCRETE AGGREGATE
CONDUCTIVITY OR VALUE OF K EXPRESSED IN B.T.U. PER HOUR PER SQ. FT. PER 1-INCH THICKNESS PER 1° FH. DIFFERENCE
NO. 1 CORKBOARD-FLAX-LI-NUM-INSO-BOARD-MASONITE-CELOTEX-ETC. K = 0.33
NO. 2 HAYDITE INSULATING FLOOR AND ROOF FILL
NO. 3 HAYDITE STRUCTURAL CONCRETE
NO. 4 COMMON BRICK BACKUP
NO. 5 FACE BRICK
NO. 6 CONCRETE SAND AND STONE AGGREGATE
NO. 7 STONE-SLATE-MARBLE
VALUES OF (U) ARE BASED ON THE INTERNAL CONDUCTIVITIES OF THE MATERIALS AS SHOWN ABOVE.
HAYDITE CHEMICAL ANALYSIS
HAYDITE AGGREGATE
SIZE WEIGHT PER CU. FT.
APPROX.
VALUES FOR SHEAR, BOND COMPRESSION AND TENSION SAME AS ORDINARY CONCRETE.
CHART SHOWS COMPARATIVE VALUES OF (U) OR OVERALL COEFFICIENTS OF HEAT TRANSMISSION EXPRESSED IN B.T.U. PER HOUR PER SQ. FT. PER 1° FH. DIFFERENCE IN TEMPERATURE BETWEEN THE AIR ON THE TWO SIDES OF THE WALLS AS PER THICKNESS INDICATED AND ARE BASED ON AN OUTSIDE WIND EXPOSURE OF 15 MILES PER HOUR.
SURFACE COEFFICIENTS USED
AND
WALL THICKNESS
AUTHORITY FOR VALUES OF K ON HAYDITE CONCRETE TAKEN FROM TESTS BY F.C. PEEBLES AND THE THOMPSON & LICHTNER CO. INC.
HYDRAULIC PRESS BRICK CO.
W. E. BARNEY

..30. The rate of heat flow thru the sample was obtained by the Flat Plate method which gives the internal coefficient of heat conductivity surface to surface. This latter value probably represents a more nearly correct factor for practical use than is represented in the other values given. It has the added advantage of being a median of all tests and was determined upon a unit probably representing the average properties of a commercial unit.

Mr. W. Chester Smith, C. E., manager Engineering Division, Cooksville Company, Limited, in a paper read before the A.S.H.V.E., presented the mechanics for the determination of a monetary evaluation of heat loss. In arriving at a factor of "100 sq. ft. exposed wall or roof per average annual heating period per one B.T.U. heat loss, per degree temp.". This is more completely explained in the following paragraphs extracted from Mr. Smith's paper:

"In the vicinity of Toronto, the average heating period is about seven months, or say 208 days, or say 5,000 hours, at an average difference in temperature of 37° F. (70° inside, 33° outside) or 7,700 degree-days or, perhaps more conveniently, 185,000 degree-hours. Multiplying this by 100 sq. ft. produces 18,500,000 degree-hours per 100 sq. ft. per year. From this may be derived the convenient average factor of 18,500,000 B.T.U.'s heat loss per year per 100 sq. ft. per 1 B.T.U. heat loss or "U", being the determined Coefficient of heat transmission per sq. ft./hr./1° diff. in temp.

"Another case now under consideration refers to an important building in Northern Ontario where the costs of materials and fuels are much higher than in Toronto and where the heating period extends over the whole year, the average temperature difference being 38° for 8,750 hours, the number of degree-hours being 332, 500 per year.

Thus - 8,750 hours x 38° x 100 sq. ft. equals 33,250,000 B.T.U.'s x "U"

33,250,000 B.T.U.'s equal 2 tons of soft coal equals $20.00 per year at $10.00 per ton.

Thus - if the heat loss "U" is 0.25, the coal required is .5 tons or $5.00 per 100 sq. ft. of exposed area or $750.00 per year for 15,000 sq. ft. involved. A saving by reducing "U" by 0.10 B.T.U.'s equals $300.00 per yr. or $3,000.00 in ten years or $6,000.00 in twenty years. At simple 5% interest, the saving of $300.00 per year indicates roughly that $6,000.00 can properly and economically be expended on the building to equal the saving in fuel."

The Diagram "Insulation Value of Haydite Concrete" was prepared by Engineer W. E. Barney.

ACOUSTIC PROPERTIES

A majority of the tests conducted to determine the sound insulation properties of Haydite building units have been conducted by Dr. Paul E. Sabine of the Riverbank Laboratories, Geneva, Illinois. Regarding these tests Dr. Sabine states:

"Haydite partition units show the greatest number of sensation units in sound reduction of the five leading types of partition materials, such as hollow clay, gypsum tile, plaster on metal lathe, and plaster on wood lathe and wood studs; conversational speech can be faintly heard but not understood and the sound of a phonograph is almost completely extinguished thru the Haydite partitions."

In Table XXXIII the results of the various tests are designated by group numbers.

Group I. Tests conducted by Dr. Sabine in which the average sound reduction is given in terms of "decibels".

Group II. Riverbank Laboratories. Coefficient of sound absorption on exposed unpainted unit. These data were obtained by the Reverberation Method at Pitch 512, the standard of efficiency being taken as an open window with a coefficient of 1 or 100% absorption.

Group III. Conclusions are given in "decibels". In explanation Dr. Sabine states:

"In order to arrive at conclusions that should be sound, these tests cover the whole range of frequencies from 128 to 4096 vibrations per second and from 128 to 1024 vibrations per second. In order to express the results of these tests by a single mechanical value, the standard practice of taking the average has been adopted. The average values for the average partitions

GROUP I. AVERAGE SOUND REDUCTION	SOLID UNITS		HOLLOW UNITS	
	No Plaster	1-inch Plaster	No Plaster	1-inch Plaster
12" Haydite Block Wall	56	58	52	54
8" Haydite Block Wall	51.6	53.7	47.8	60.5
6" Haydite Block Wall	49	51.6	44.8	48.5
4" Haydite Block Wall	45	48	37	43
3" Haydite Block Wall	42	46	36	42

GROUP II. COEFFICIENT OF SOUND ABSORPTION – PITCH 512
Haydite Units Exposed = .37

GROUP III. SOUND INSULATION FOR PARTITION WALLS	
1. 4" Haydite partition units, 1" Gypsum plaster	Average Reduction
Pitch 128 –4096	38.0
Pitch 128 –1024	36.1
2. 8" Haydite Building Units, 1" Gypsum plaster	
Pitch 128 –4096	40.1
Pitch 128 –1024	37.2

GROUP IV. ABSORPTION COEFFICIENT USING LARGE AREAS OF MATERIAL IN REVERBERATION ROOM

4x8x16" partition units

	Pitch 250	500	1000	2000	4000
Wall H-1	0.58	0.56	0.33	0.51	0.50
Wall H-2	0.42	0.70	0.33	0.54	0.51

Detail of Aggregate and Physical Properties of Units

	H-1	H-2
1. Fineness Modulus	3.5	4.50
2. Dry Rodded Weight	54.0	49.6
3. Cubic Feet Dry Rodded Aggregate used per sack of cement	9	9
4. Weight of Dry Concrete, p.c.f.	67.5	59.5
5. Compressive Strength, p.s.i., gross area	880	610
6. Water Absorption		
(a) Percentage of dry wgt. of conc.	20.5	15.3
(b) Per cent per vol. of c.	22.2	14.5

GROUP V. RIVERBANK LABORATORY – 1936.

	Pitch 128	256	512	1028	2048
4x8x16 Haydite Tile	.29	.40	.71	.43	.43

Table XXXIII

tested are taken as the measure of their relative sound insulating merits."

Group IV. Results of tests conducted by F. R. Watson, Professor of Experimental Physics and Keron C. Morrical, Research Assistant, University of Illinois and published in the A.C.I. (1936) Proc. as the article "Sound Absorption Value of Portland Cement Concrete". These values are given as Absorption Coefficient and the physical properties of the units indicated in the tests are made a part of the table.

Group V. Results of tests at the Riverbank Laboratories on February 22, 1936 using a 4x8x16" Western Haydite tile. These tests were conducted according to their standard procedure of measuring the effect on the rate of decay of sound in their sound chamber on a 72 sq. ft. sample of material. These values are given in terms of Absorption Coefficients.

It will be noted that part of the values are in terms of "decibels" and part in terms of "absorption coefficients". The latter is directly applicable in the equation "$T = 0.05$ times volume divided by absorption" for computing the time taken for an average sound to die out in a room. Complete explanation of the units and their uses is given in Dr. Sabine's treatise "Acoustics in Architecture" published by the McGraw-Hill Book Company.

COLUMNS

Under the sub-heading Pilasters the results of tests conducted at the Ohio State University have been given which are applicable to the design of columns or pilasters supporting trusses or other roof members. In the design of masonry unit structures it is believed that an advantage can accrue from the use of filled core piers or columns. A diagram of two such piers is shown in Figure 35.

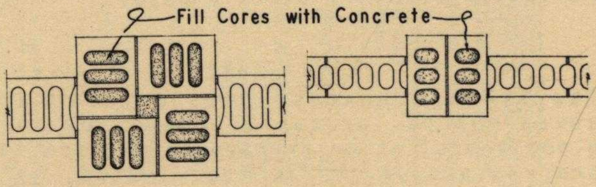


Fig. 35

EXPANSION JOINTS

All concrete construction, whether monolithic or precast, must obey the laws of temperature movement and, therefore, some provision must be made for contraction and expansion when using masonry units. Where the uninterrupted length of wall is of a length sufficient to contribute to an appreciable movement some form of expansion joint should be injected to care for the computed linear expansion. In Figure 36 the details of three proposed expansion joints are shown. The use of thermal coefficients of expansion per degree F. obtained during the University of Wisconsin tests will reflect correct design procedure.

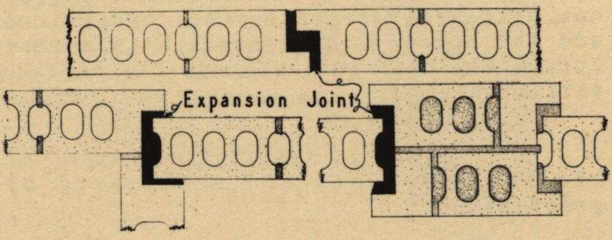
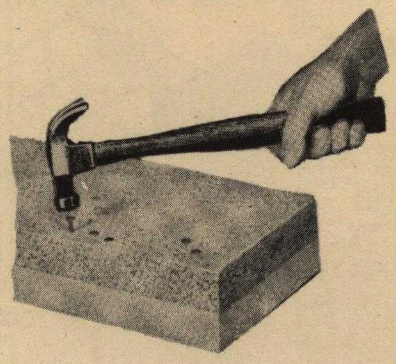


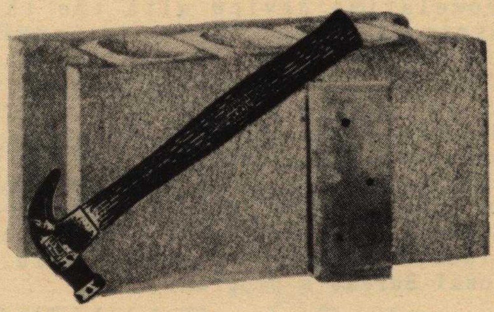
Fig. 36

NAILABILITY

A substantial economy in construction, using Haydite masonry units, results from the fact that wood trim, furring, etc., can be nailed directly to the units. Nails driven into the block will not loosen and, furthermore, there is no danger of rusting of the nails.

During an investigation conducted at the South Park laboratory of the Hydraulic-Press Brick Company advantage was taken to conduct a test on the "nailability" of Haydite units. The units used in this test were obtained from the commercial stock of a block company and the results of the tests are shown in Table XXXIV.





KIND & SIZE NAILS	DEPTH NAILS INSERTED THRU 3/4" BOARD	LB. PULL TO EXTRACT NAIL 1/4" 1st PULL	LBS. PULL TO EXTRACT NAIL 1/4" 2nd PULL	CONDITION OF NAIL AFTER 2nd PULL	LENGTH OF TIME NAIL INSERTED
6 Com.	1-1/4"	165	110	Tight	At Once
"	"	160	110	"	"
"	"	125	90	Loose	"
"	" *	95	80	Tight	"
"	"	100	70	Loose	"
"	"	110	45	"	"
"	" *	0	0	Out	"
"	"	170	105	Loose	"
"	"	140	70	Tight	"
"	"	120	130	"	"
	Average	118.5	81.0		

* Nail bent in starting.

Table XXXIV

TESTS IN PROGRESS

FIRE TESTS: There is now (April 1940) a series of tests in progress at the National Bureau of Standards sponsored by the National Concrete Masonry Association to develop the following information:

1. Fire retardant period of "solid" concrete masonry partitions, plastered and unplastered, 3", 4" and 6" thickness, "solid" units being defined as units having more than 70% net area.

2. Fire retardant periods for hollow, non-load-bearing partitions of 4", 6" and 10" thickness.

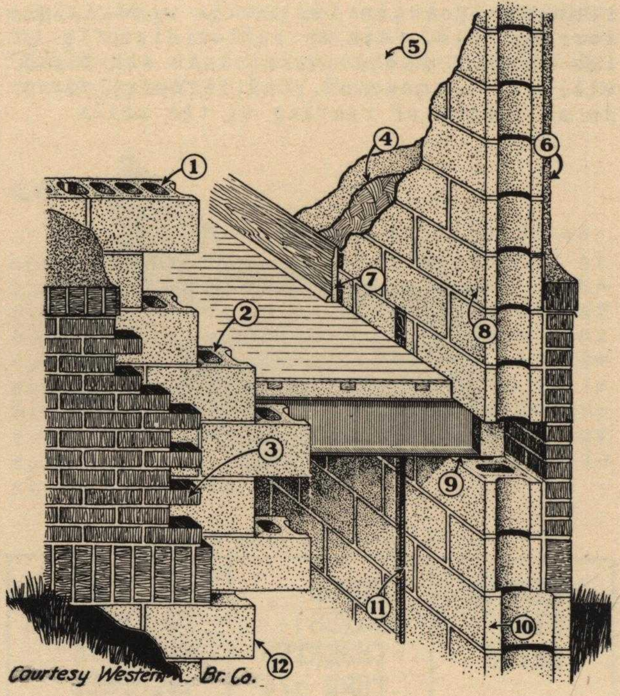
3. Fire retardant period of hollow double wall built with 4" hollow concrete masonry partition units having a 2" air space.

4. Fire retardant periods for face brick walls backed with 6" hollow load-bearing concrete masonry units having a total wall thickness of 8-1/2" and 10".

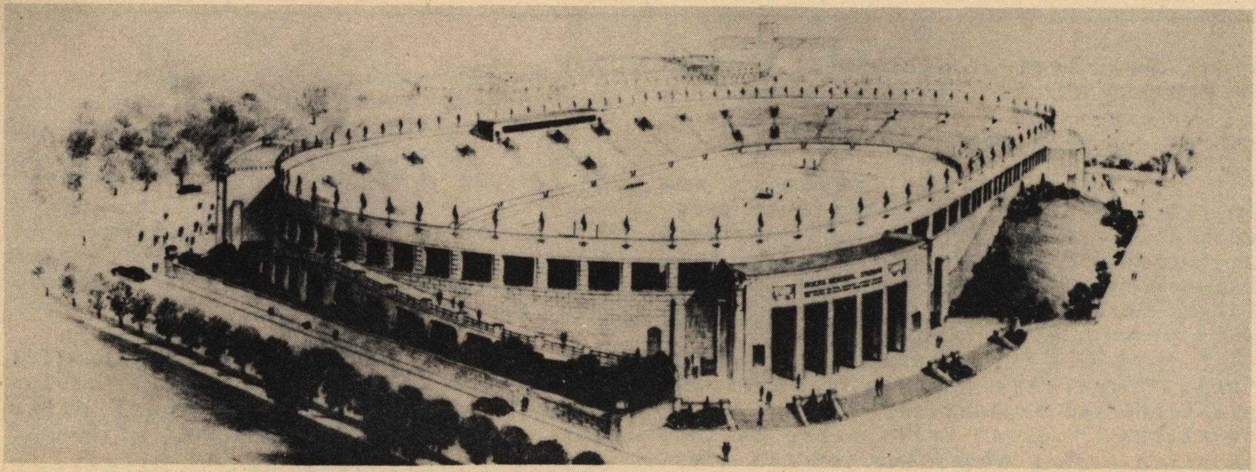
5. Fire tests of concrete masonry units made with 5 different aggregates: Cinders, Haydite, Pottsco, Waylite and sand and gravel.

RAIN RESISTANCE TESTS: Tests are being conducted at the National Bureau of Standards to determine the rain resistant properties of 8x8x16" Haydite masonry units produced on a Besser tamper equipped with a Straub ostrowelating device with the three sponsors (American Aggregate Company, Besser Manufacturing Company and Mr. F. J. Straub, (Straublox,) producing the units and erecting walls at the Bureau of Standards Laboratory. The intent is to so grade the aggregate that the resulting product will be a dense impervious unit and to further insure its impervious character by "ostrowelating", substantiating its performance thru the National Bureau's program.

Upon the completion of both tests the National Bureau will publish the results as "Building Materials and Structures Reports". Prior to the publication the information may be obtained from the Bureau of Standards upon the request of any other Federal division or Municipal authority.



1. Large, lightweight units cut dead loads and save labor costs.
2. Highly rated for fire-safety. Haydite has no combustible content.
3. Ideal back-up for face brick, stone and other facing materials.
4. Splendid plaster base. Saves furring, lathing, plaster and labor.
5. Danger of plaster cracks and blemishes reduced to minimum.
6. Stucco applied directly to units; "Insul-Brick"; Asphalt, or Asbestos siding nailed direct to units presents an excellent exterior at minimum cost.
7. Trim nailed directly to units saves nailing plugs and strips.
8. Effective sound and heat insulation without extra cost.
9. Load bearing strength fully meets local building codes.
10. Limited capillarity assures dry interior wall surfaces.
11. Units are cut and channelled easily without danger of breakage.
12. Units are true and absolutely uniform in all properties.



One-half mile of Haydite Units

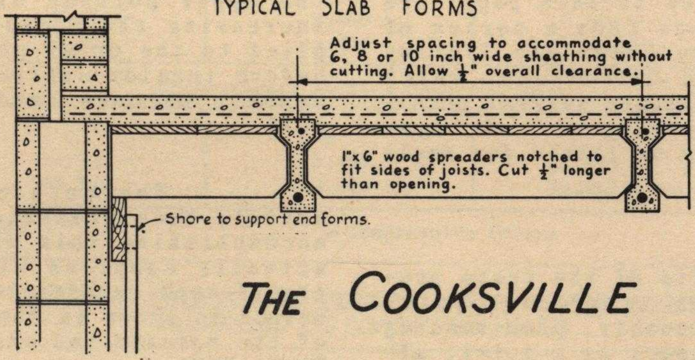
PRECAST JOIST

The manufacture of precast Haydite joists has offered a lucrative side line to many product plants.

The joists are generally poured from standard P.C.A. designs, although some manufacturers have their own designs and have profited sufficiently thereby to justify publication of engineering data some of which is reproduced herein.

The Cooksville Company, Limited, thru its Engineering Department, managed, by Mr. W. Chester Smith, C.E., has designed a joist and floor system and has computed tables showing the properties applicable to design using this joist and floor system which, it is believed, will be of general interest to Haydite manufacturers. Thru permission of that company it is reproduced here.

TYPICAL SLAB FORMS



THE COOKSVILLE CO. LTD.

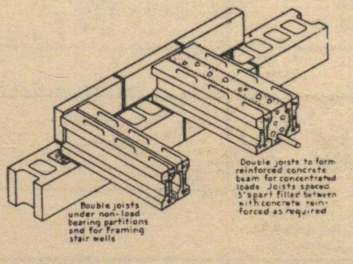
TABLE FOR DESIGN OF PRECAST HAYDITE JOIST-SLAB FLOORS

Joist Depth in.	Thickness of Str'l. Floor	Bottom Bar Rd.	Resisting Mom't. in.-lbs.	Maximum Shear lbs.	Joist Spacing in.	Slab Thickness in.	Dead Load Joist & Slab lb. per sq. ft. — Haydite Conc. Slab	Dead Load — Stone Conc. Slab	Total Safe Load (Live and Dead) including Joist & Slab—lb./sq. ft. — SPAN IN FEET 11	12	13	14	15	16	17	18	19	20	21	22	23	24
8″	10″	⅝″	44,500	1,610	20	2	25	33	147	122	102	86	74	..	..							
"	"	"	"	"	24	"	23	31	121	100	84	72	..	..	...							
"	"	"	"	"	27	"	22	30	109	90	75	..	..	..	..							
8″	10″	¾″	62,600	1,920	20	2	25	33	..	173	146	124	106	92	..							
"	"	"	"	"	24	"	23	31	172	143	121	102	88	76	..							
"	"	"	"	"	27	"	22	30	154	128	107	91	78	..	..							
"	10.5″	"	66,400	2,040	30	2.5	26	36	142	117	97	81	..	..	..							
10″	12″	¾″	78,000	2,390	20	2	26	34	..	..	162	140	121	107	95							
"	"	"	"	"	24	"	25	33	..	158	135	116	101	88	78							
"	"	"	"	"	27	"	24	32	165	139	119	103	89	78	..							
"	12.5″	"	81,000	2,510	30	2.5	27	37	153	129	109	93	80	..	..							
									Area & Weight per ft. of Rd. Steel Bars — Size	Area	Wgt. lbs.					SPAN IN FEET 18	19	20	21	22	23	24
10″	12″	⅞″	105,600	2,380	20	2	26	34				..	..	164	145	128	114	102	...	..	..	..
"	"	"	"	"	24	"	25	33				..	157	137	121	107	95	84	..	..	..	..
"	"	"	"	"	27	"	24	32				157	139	121	106	94	84	74	..	..	..	..
12″	14″	⅞″	126,500	3,320	20	2	32	40	¼″	.0491	.167	..	..	..	177	156	139	124	112	102	92	..
"	"	"	"	"	24	"	29	37	⅜″	.1105	.376	..	..	169	149	133	117	105	94	85	..	..
"	"	"	"	"	27	"	28	35	½″	.1963	.668	..	172	150	132	116	104	93	83	..	..	..
"	14.5″	"	132,000	3,460	30	2.5	31	41	⅝″	.307	1.043	182	158	137	120	107	94	84	..	..	..	..
12″	14″	1″	166,000	3,310	20	2	32	40	¾″	.442	1.502	..	..	..	..	..	183	164	148	134	122	112
"	"	"	"	"	24	"	29	37	⅞″	.601	2.044	..	..	..	..	172	155	139	125	113	103	94
"	"	"	"	"	27	"	28	35	1″	.785	2.67	...	..	..	172	153	136	122	110	100	91	82
"	14.5″	"	173,000	3,450	30	2.5	31	41	1⅛″	.994	3.38	..	..	181	160	142	126	112	100	91	..	..

NOTE—Deduct from total safe loads given in Table the dead load of joists and slab, floor finish, ceiling, partitions, etc., to determine safe live load capacities.

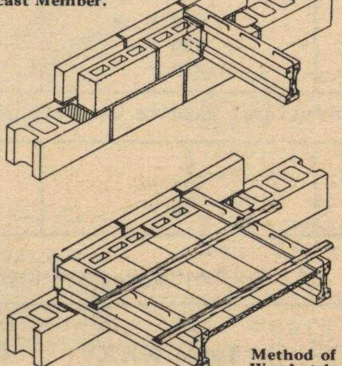
All the calculations are based on Code of the American Concrete Institute with 3,000 lbs. concrete and intermediate grade steel.

Resisting Moment and Maximum Shear are approximate and based on "T" beam section and "j" = ⅞. Load capacities may be properly increased by: thickening webs of joists towards ends; hooking of tension steel; supporting joists at mid-span until concrete slab hardens. For spans of 20′ or more, put one row of bridging at mid-span. Slab reinforcement ¼″ round rods at 9″ to 12″ centre to centre at right angles to joists and at 18″ centre to centre parallel to joists, or wire mesh of equivalent sectional area.

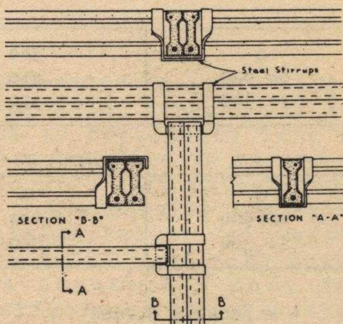


Methods of framing joist to increase load capacity.

Bridging—4″ x 8″ x 15¾″ Haydite Blocks or Brick or Precast Member.



Method of attaching wood nailing strips. Wood strips wired to top of stirrups.



Framing details for Stairwells, etc.

PRESTRESSED REINFORCED JOIST

Tests were conducted at Purdue University, the results of which appear as the paper "Prestressed Reinforced Concrete Joists under Loading Tests" by R. E. Mills and W. B. Miller published in A.C.I. Journal 1939. The authors explain:

"Presented in this paper are data and conclusions from a series of studies made at the Materials Testing laboratory, Purdue University, which were designed to evaluate several possibilities in the development of light weight precast beams or joists for small house construction."

The results of the tests present an innovation in precast joist practice. Unquestionably, prestressing of a small member, such as a joist, affords an opportunity to develop a new field for reinforced concrete and members so designed will permit handling of the units with less danger of damage. It provides for a balanced strength relation between concrete and steel which should result in a saving of material and permit increased span lengths. Tensile stresses may be eliminated from the concrete in beam or joist members by proper prestressing thus utilizing the strength of the entire cross-section of the unit and postponing the occurrence of cracks. The use of the term "prestressing" has been adopted to advertising literature for various forms of roof and floor slabs, but it is doubtful if there is any evidence of actual prestressing in these instances. That is to say, placing that portion of the beam below the neutral axis in initial compression so that this compression is relieved as compression is applied to the upper portion of the beam, thus, increasing the moment that can be applied to the upper portion of the beam before tension sufficient to crack the members becomes evident in the lower half.

The authors of the A.C.I. article have presented a novel way of accomplishing this prestressing which actually complies with the theory of prestressed reinforced concrete. Their method is shown in Figure 37. A summary of the moments and stresses is given in Table XXXV.

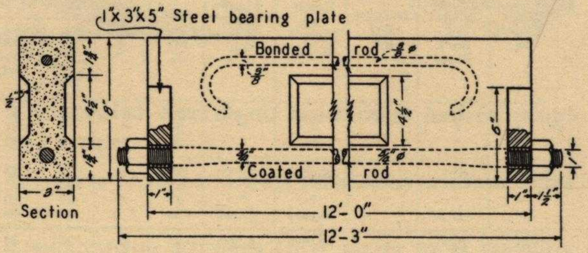


Fig. 37

SUMMARY OF CONCRETE STRESSES

External Moment inch lb.	Top of Joist		Bottom of Joist	
	Measured Stress p.s.i.	Theoretical Stress p.s.i.	Measured Stress p.s.i.	Theoretical Stress p.s.i.
Prestressed Haydite Concrete Joist				
0	340 +	150 +	900 −	670 −
24,900	410 −	530 −	150 −	350 −
51,300	1,350 −	1,250 −	650 +	10 −
Conventional Haydite Concrete Joist				
0	0	0	0	——
24,900	1,120 −	730 −	cracked	——
51,300	2,050 −	1,520 −	cracked	——
+ = Tensile Stress		− = Compressive Stress		

Table XXXV (continued on next page)

SUMMARY OF STEEL STRESSES

External Moment inch lb.	Steel, Top of Joist		Steel, Bottom of Joist	
	Measured Stress p.s.i.	Theoretical Stress p.s.i.	Measured Stress p.s.i.	Theoretical Stress p.s.i.
Prestressed Haydite Concrete Joist				
0	2,800 +	800 +	11,700 +	11,700 +
24,900	7,300 -	5,900 -	16,300 +	14,200 +
51,300	18,200 -	12,800 -	21,100 +	16,800 +
Conventional Haydite Concrete Joist				
0	0	0	0	0
24,900	11,300 -	6,100 -	10,600 +	9,600 +
51,300	20,700 -	12,600 -	23,600 +	19,800 +
+ = Tensile Stress		- = Compressive Stress		

SUMMARY OF DEFLECTION MEASUREMENTS SHOWING RELATION BETWEEN PRESTRESSED AND CONVENTIONAL JOISTS

	Deflection Measurements, Inches	
External Moment inch lb.	Prestressed Concrete Joist	Conventional Concrete Joist
0	n 0.129	0.000
24,900	p 0.048	p 0.202
51,300	p 0.211	p 0.410
n = Negative Deflection	p = Positive Deflection	

Table XXXV (continued)

PRECAST ROOF SLABS

The construction of precast roof tile or roof slabs furnishes a market for considerable Haydite tonnage and several large firms are devoted exclusively to the manufacture and erection of the product. The Federal-American Cement Tile Company, Chicago, Illinois, has constructed roofs and floor slabs, under the trade name "Featherweight", over a considerable portion of the central United States. They issue a fully explanatory manual (Catalog 103) which should be in the hands of every designer. One of the F-A roof slabs is shown in Figure 38.

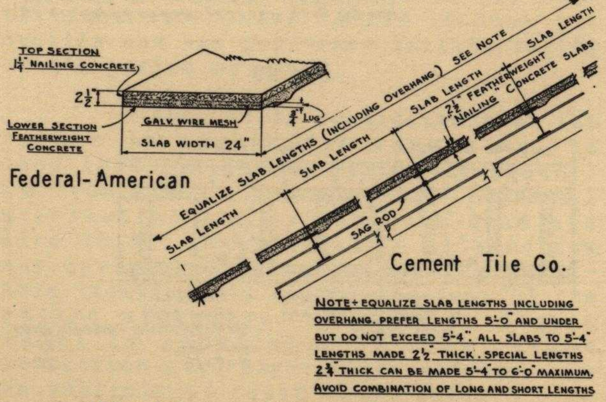


Fig. 38

The Cooksville Company, Limited, of Toronto, Ontario, Canada, has its own design which is reproduced here as Figure 39. It has supplied in excess of 4,000,000 sq. ft. with very satisfactory results. Their table showing the value of Heat Transmission factor "U", which is reproduced with the roof slab drawing, furnishes convenient data for computing the efficiency of this type roof deck for Thermo Insulation by using Mr. Smith's mechanics, explained in Thermal Properties, Masonry Unit division. (Fig. 39 shown on page 66)

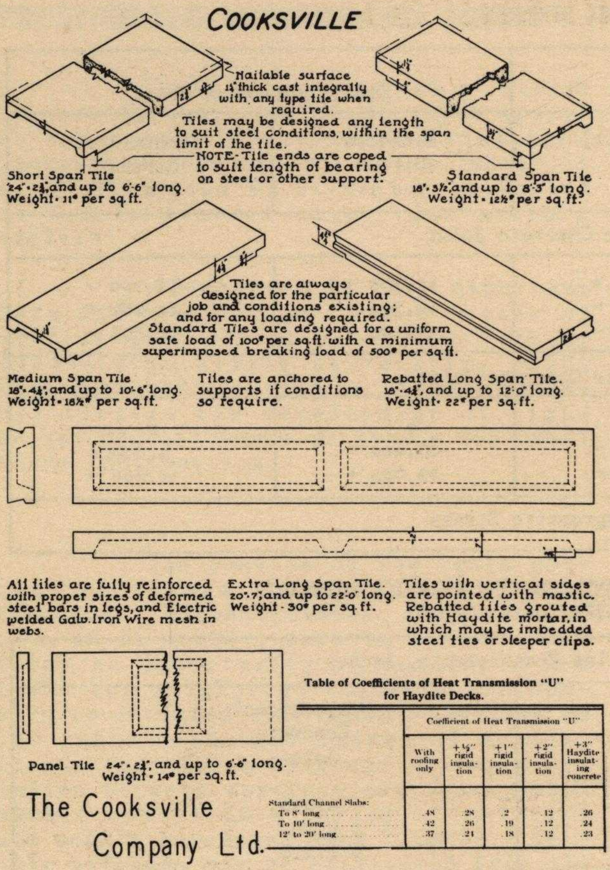


Table of Coefficients of Heat Transmission "U" for Haydite Decks.

	Coefficient of Heat Transmission "U"				
	With roofing only	+½" rigid insulation	+1" rigid insulation	+2" rigid insulation	+3" Haydite insulating concrete
Standard Channel Slabs:					
To 8' long	.48	.28	.2	.12	.26
To 10' long	.42	.26	.19	.12	.24
12' to 20' long	.37	.24	.18	.12	.23

Fig. 39

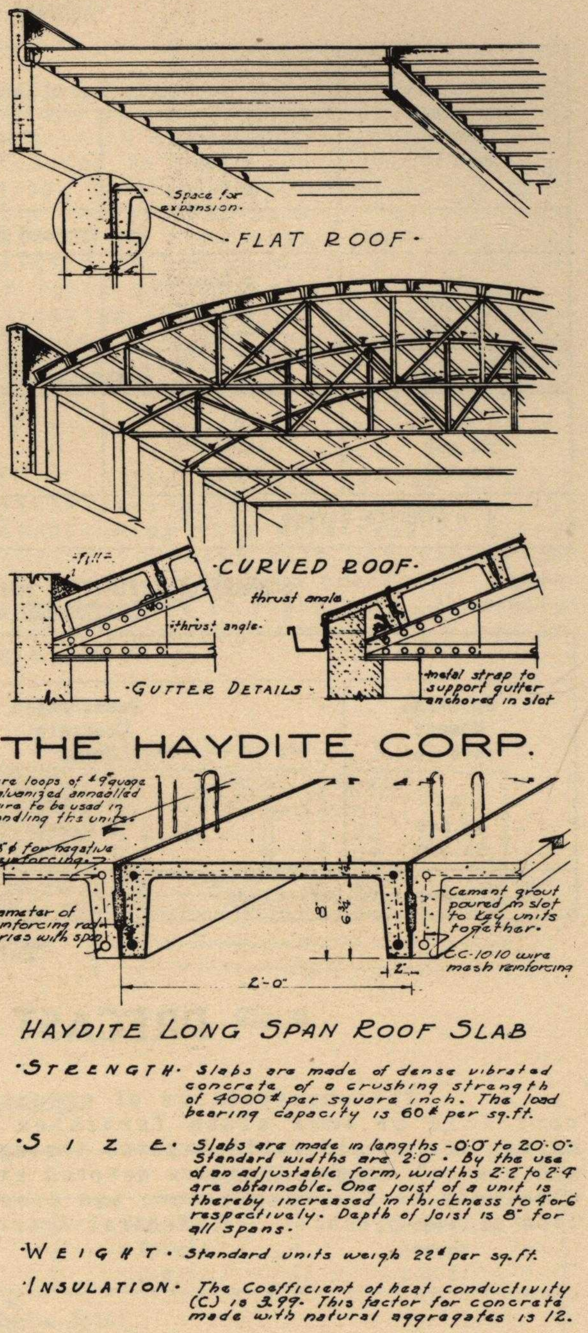


Fig. 40

The Haydite Corporation of Kansas City, Missouri, manufactures and constructs the type of roof deck shown in Figure 40.

FLOOR SYSTEMS

A design using Haydite floor units and Haydite light weight concrete, which reduces dead load from 25% to 40% as compared with ordinary tile joist construction, has been promoted by the Western Brick Company. A typical section of the construction is shown in Figure 41.

The material Haydite is commonly specified in federal and municipal specifications for floor fill. This specification generally can be met by using the factors, given under Structural Concrete, subheading "Low Strength Concrete", for values of total water, cement and aggregate quantities.

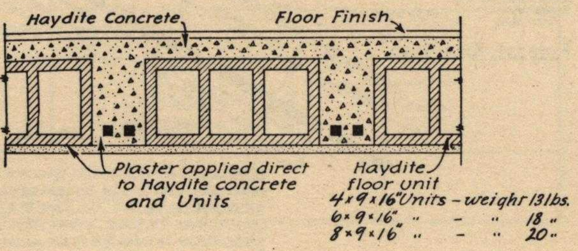


Fig. 41

PLASTER AND STUCCO

The physical property that enables Haydite concrete to perform in actual service with much better results than could be expected with natural aggregate concrete, and which property is also exhibited in the tests on Masonry units, offers the same endurance factors when used as the "sand" fraction for plaster or stucco. In addition to the ability to resist destructive elements it has acoustical and thermal values far superior to any other type of plaster.

One of the earlier licensees in the industry used approximately 9,000 cubic yards of the material as both plaster and stucco very satisfactorily. The grading used for this particular work is shown in Figure 42.

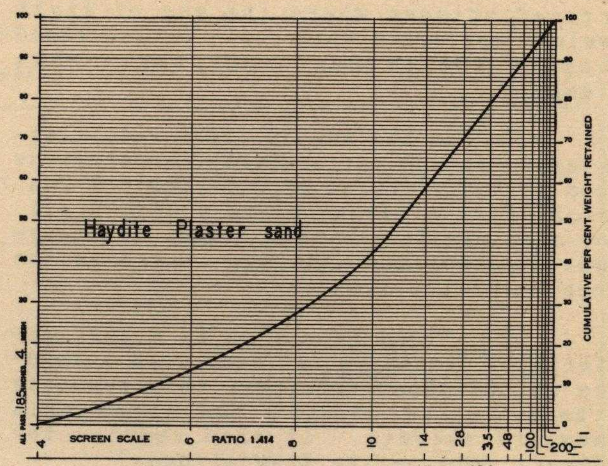
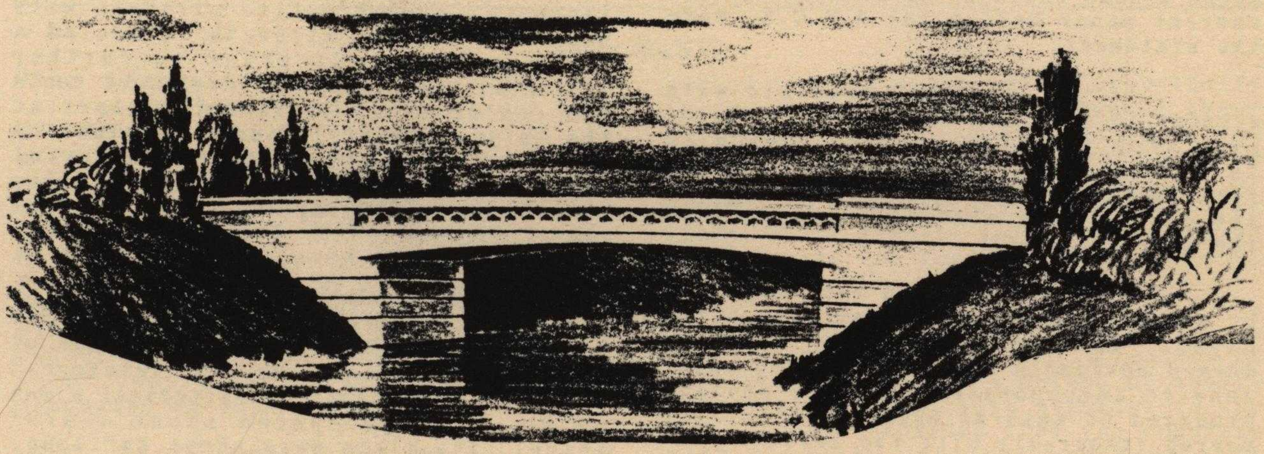


Fig. 42

BRIDGES AND BRIDGE FLOORS



Haydite aggregate concrete has been used in bridge floors and in the construction of entire bridges since the beginning of its manufacture. A list of bridge jobs on which the material has formed some part is too extensive to enumerate. In practically every place where Haydite has been used it has contributed a decisive factor in cost reduction and has performed satisfactorily over a period of years.

When it is considered that the stress in any bridge caused by the dead load (weight of structure itself) is from 50% to 80% that of the total stresses of the bridge both dead and live loads, it can readily be seen how any saving in the weight of the structure itself would reduce the cost of the entire structure. The lower figure (50%) is applicable to steel frame structures with light floor systems. In an analysis of rigid frame bridges: As a rough approximation in single span highway bridges, at the knee, 60% of the stresses are due to dead load, 30% to live load and 10% to shrinkage and change of temperature. In the center, stresses from these three sources, are usually more nearly equal than they are at the knee. With such an amount of stress necessary to maintain the supporting structure any amount of decrease in the amount of the weight of the structure itself, must of necessity, tend to reduce the dead load stress.

Inasmuch as Haydite has shown an adaptability to work in conjunction with other aggregate concretes there is no reason why a combination of "Natural aggregate concrete, - Haydite aggregate concrete" could not be incorporated in the design of rigid frame bridges, or that Haydite concrete could be used as the super structure and natural aggregate concrete as the sub-structure in the design of other types of concrete bridges. Haydite concrete might like-

wise have a useable place in the design of the recently developed "timber-concrete" bridges where the use of light weight aggregate span could be increased beyond the present acceptable span lengths.

In the use of light weight aggregate on one particularly large bridge job it was reported (A.C.I. Journal Jan. 1938) that a saving of 25 pounds p.s.f. or 1450 pounds per lineal foot of bridge was accomplished. It was stated in the report of the structure:

"This reduction in weight materially decreases the dead load stresses in the superstructure, thus reducing the area and cost of the structural members therein. It also reduced the direct load on the foundations."

Prior to the production of Haydite at various places a nationally known bridge engineer in commenting on a current paper before the A.S.C.E. made the statement:

"It was found possible with economy to ship such light weight aggregate from its point of production in Kansas City, Missouri, as far as San Francisco, California and Canada and in the latter case also to pay a duty on the aggregate."

This condition was supported by other authorities commenting on the paper. In some sections it has been deemed advisable by the designing engineer to incorporate a wearing surface produced of natural aggregate concrete poured integrally with the Haydite concrete floor.

In the "Illinois series" tests were conducted on "bonding of floor finishes". In no test did the finish crack loose from the base before the ultimate load was reached. The finish in both Haydite and gravel concrete slabs remained integral with the base with deflections considerably in excess of one inch on a four foot span. At final failure with deflections of about 1-1/4", crushing of the 3/4" finished course, occurred in the middle third near one of the load points and a section of finished concrete split off. The section which split off from the Haydite slab had portions of the base adhering to the top, the fracture being mostly below the top. This seems to prove that a topping can be applied to a Haydite concrete bridge floor and accomplish both lightness of weight and a wearing surface in combination with a particular Department specification. It also evidences the possibility of designing structures using both types of concrete.

A series of tests is now under way, which, when completed, will probably be published in A.C.I. Journal, on a combined "concrete-timber beam" using concrete as the compressive section and timber as the tensile portion, bonding by diagonal plates driven into the timber section. While a majority of the tests were made using natural aggregate concrete there is every reason to believe that Haydite aggregate concrete would furnish a superior product for the compressive section.

Some objection to the use of Haydite concrete for bridge flooring has been raised due to the results of a series of tests conducted by the Bureau of Public Roads and published in the December 1931 issue of "Public Roads" during which it was discovered that while the material showed a continual increase in compressive strength with age the flexural strength reflected a retrogration. In order to further determine this feature a series of tests was conducted by Professor Richart at the University of Illinois on slabs up to five years of age, the results of which are shown in Table XXXVI. His comments accompanying the report of this test follows:

"The slabs tested were made by the Federal-American Cement Tile Company, Chicago, Illinois, and were made of HAYDITE concrete. They were reinforced with wire mesh having longitudinal wires of No. 12 gage spaced about 1-3/8" apart. The slabs were about 52" long, 24" wide and 1-1/4" thick, with added thickness in the form of a heavy raised rib at middle and small ones at the edges. The computed section modulus of these slabs is about 14.5 in. and the values of modulus of rupture have been computed from this figure. Of the load given above, about 110 lb. was the weight of the slab, uniformly distributed, and the remainder was a concentrated load at the middle of the 48-in. span.

"The slab was supported at one end on an I-beam and on the other by the platform of a Toledo scale which weighed the reaction. A loading strip about 3" wide was built of plaster of Paris at midspan and load was applied gradually on the full width of slab through an I-beam."

In 1937 the Department of Public Roads again conducted a series of tests which were published as "The Effect of Curing Conditions on Strength of Concrete Test Specimens Containing Burnt

BRIDGES AND BRIDGE FLOORS

DEPARTMENT OF THEORETICAL AND APPLIED MECHANICS

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

URBANA

SLAB NO.	DATE MADE	AGE AT TEST	LOAD AT FIRST CRACK LBS.	ESTIMATED MODULUS OF RUPTURE LBS./IN.SQ.	REMARKS
0	4-25-27	5 yr.	...	...	Cracked before test
1	4-25-27	5 yr.	516	380	
2	4-25-27	5 yr.	580	435	
3	4-25-27	5 yr.	...	...	Cracked before test
4	4-25-27	5 yr.	...	...	Cracked before test
5	2-18-31	1 yr-2 mo.	524	390	
6	2-18-31	1 yr-2 mo.	660	500	
7	2-11-31	1 yr-2 mo.	640	485	
8	3-3-32	34 days	648	490	
9	3-3-32	34 days	624	460	
10	3-3-32	34 days	650	490	

Table XXXVI

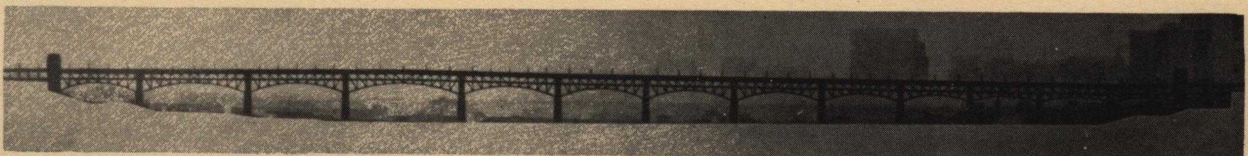
Clay Aggregates" (Public Roads, May 1937). In this article mention was made of the findings of the results of the previous test and it was stated:

"In view of the probability that this behavior of the Haydite specimens might be related to the moisture retaining qualities of the aggregate, it was decided to conduct further studies of Haydite concrete specimens. An experimental series of laboratory tests under controlled curing conditions is discussed in this report."

In summarizing the results of the last series the author states:

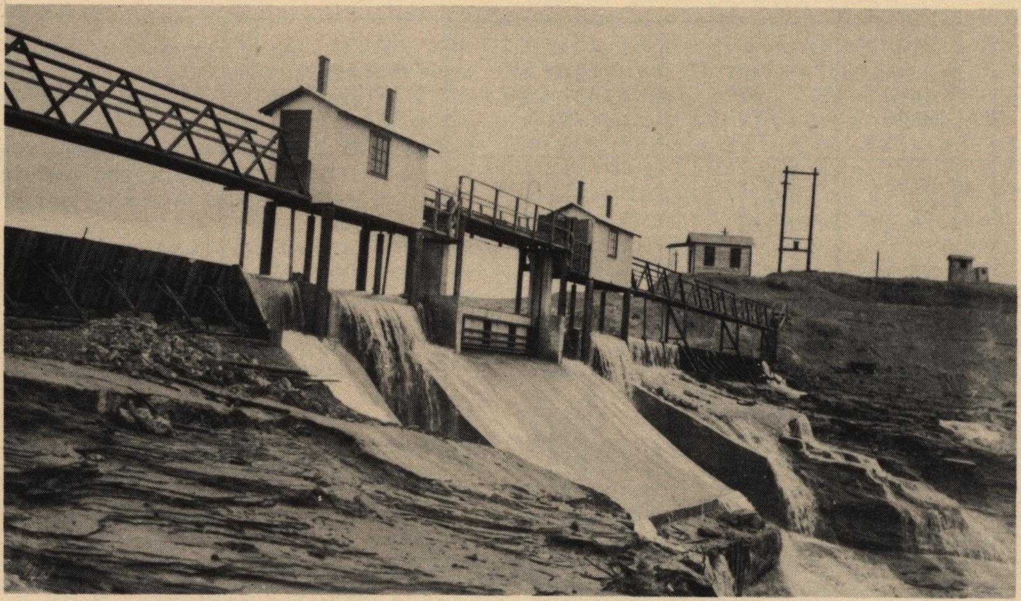
"The very peculiar behavior of the Haydite concrete here indicated is believed to be caused by internal moisture stresses * * * These initial stresses of course tended to reduce the load required to produce failure in bending, resulting in an observed modulus of rupture considerably lower than would have been obtained if the moisture content of the specimens when tested had been the same throughout. The fact that the strengths after 180 days in air curing increased materially probably resulted from the fact that during this period the specimens had an opportunity to dry uniformly, thus relieving these moisture stresses. That this so-called 'shell' effect is of great importance in influencing the observed modulus of rupture will be evident from consideration of the results for specimens cured for 6 months and for 1 year."

Several concrete technicians have believed that the "shell" effect of concrete contributes a method of analyzing concrete qualities superior to the now accepted analysis thru the compressive strength property and from this belief the so-called "ball test" was developed. The originator of this theory conducted an extensive series of tests on actual construction during one construction season. A mass of data was collected, some of which did not correlate, although there was a sufficient trend in the information to lead conclusively to a belief that the enveloping shell of cylinders, walls or slabs furnish a definite factor towards their behavior in either the compression or flexural determination. Unfortunately the experiments were not conducted to a point where the experimenter felt justified in publishing the results.



Twelve thousand cu. yds. Haydite Aggregate used in Reinforced Concrete Deck

HYDRAULIC STRUCTURES



Haydite concrete has had a limited use in the construction of outlet tunnel lining and the facing of over-flow dams. In one particular case an over-flow dam faced with 3500 p.s.i. Haydite aggregate concrete performed satisfactorily over a period of years during each year of which there was ice frozen on the dam facing for periods up to three weeks and at intervals of six to seven times a season, in this manner subjecting the shell of the facing to repeated "freezing and thawing cycles" probably in excess of twenty such cycles annually. An inspection of the structure six years after its completion revealed no disintegration of the surface.

In the manufacture of concrete pipe, particularly where shipment to the place of use is required, the relative weight between Haydite concrete and natural aggregate concrete pipe (2/3) would seem to add a decisive factor in favor of its use, particularly in view of the fact that a superior pipe can be produced thru the use of Haydite.

In a pipe plant in the Pacific Northwest a small quantity of Hydraulic concrete pipe was produced by workmen who were totally unacquainted with the use of the material. The manager of that plant reported:

"We took one section from the first batch we made - the one in which we were short of fines, then we broke the one which had stood the perfect percolation test. Both of these pipes broke at 3000 pounds or 1200 pounds per foot."

NOTE: A.S.T.M. specifications for 6" sewer pipe is 1000 pounds.

PLANT CULTURE

While the adoption of Haydite as a growing medium is comparatively recent the propagation and growth of plants by sand-gravel or cinder (soil-less) culture is old.

During the past two years the Division of Floriculture of the Ohio State University has carried on extensive experiments with gravel and cinder culture in an attempt to make it applicable to commercial growth. An outline of its investigations follows:

"1. To simplify the entire system, including solutions, routines, etc.

"2. To ascertain the best solution for each group.

"3. To determine the best medium (various gravels, cinders, and Haydite).

"4. To iron out the present difficulties."

A Progress Report of its investigations was published in mimeograph sheets entitled "Gravel and Cinder Culture for Greenhouse Flowering Crops" by Arnold Wagner, Division of Floriculture, and explained the tests conducted, details of systems recommended, and the solutions applicable to soilless plant growth in addition to the prices per pound of each ingredient and the sources of supply.

Its statement of the advantages of gravel-cinder growth follows:

"1. Greatly reduced labor (no water, no weeding, no cultivation, no fertilizer, no changing of soil).

"2. Type of growth can be controlled by increasing or decreasing concentration of solution and by varying the ratios of the constituents.

"3. Largely automatic.

"4. Absence of a large number of soil-born pests and diseases.

"5. Better quality of flowers.

"6. Increased production in roses."

After many experiments it was determined that Haydite offered the best "medium" and recommendations for its use, together with details of the equipment necessary, were given in the monthly bulletin of the Ohio Florists Association, May 1939.

It was found from the numerous experiments at the Ohio State University that the aggregate corresponding to "C" grading was best adapted for plant culture and that the "AA" grading was the most satisfactory medium for the propagation of plants. Cumulative percentages of both gradings are given in Figure 43.

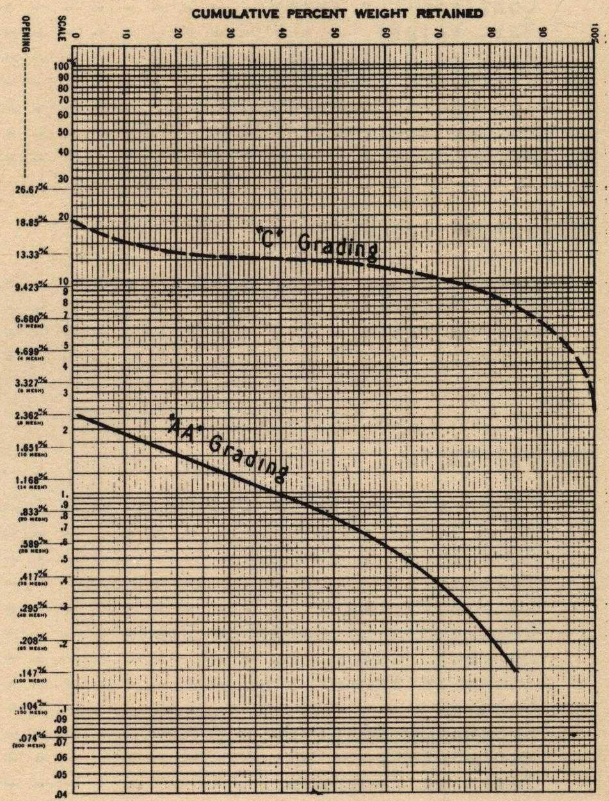


Fig. 43

Methods and detailed procedure with a full and complete explanation of the process have been explained in the volume "Soilless Culture" by Ellis and Swaney of the Ellis Laboratories, Inc., Montclair, New Jersey and published by the Reinhold Publishing Company, 330 West 42nd Street, New York City. While this publication does not mention the use of Haydite the systems explained by them are adaptable to Haydite culture.

The University Hydroponic Service, Berkeley, Cal. have prepared a complete food with plant growth hormone and the correct proportion of Vitamin B1, especially adaptable to Soilless Plant Culture which they market under the trade name "Plant-Chem."

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STRUCTURAL CONCRETE

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